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Avaliação da qualidade ecológica do Rio Mau

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Ao meu Avô Zé, que teria gostado muito de ver chegar este dia…

o júri

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palavras-chave

Rio Mau, múltiplos agentes de *stress*, estado ecológico, Directiva Quadro da Água, comunidade de invertebrados bentónicos, qualidade da água

resumo

O Rio Mau sofre a influência de vários agentes de *stress*. A poluição das suas águas é particularmente preocupante uma vez que este rio é um tributário do Rio Vouga; ambos são usados para várias actividades, incluindo captação de águas neste último. No entanto, a presença destes agentes de *stress* não garante por si só uma má qualidade ecológica, uma vez que os rios possuem uma certa capacidade de auto-depuração. O principal objectivo da Directiva Quadro da Água (DQA - Directiva 2000/60/CE, 2000) é a obtenção ou preservação do bom estado ecológico nas massas de água em todos os Estados-Membros da UE. Assim sendo, avaliar o estado ecológico do Rio Mau é necessário no âmbito da DQA. Os programas de biomonitorização, recomendados pela DQA como parte da avaliação ecológica, baseiam-se em bioindicadores, os quais são muito úteis no estudo do efeito de agentes de *stress*. Os macroinvertebrados bênticos têm sido largamente usados – e são fortemente recomendados – como indicadores biológicos da qualidade ecológica na gestão de rios. Este trabalho pretendeu estudar os efeitos de múltiplos agentes de *stress* (escorrências de minas abandonadas, efluentes domésticos e escorrências agrícolas) no Rio Mau, através da análise da variação espacial e sazonal das suas comunidades de macroinvertebrados. Foram utilizadas duas abordagens distintas: a) avaliação da qualidade da água, através do uso de índices bióticos e tendo como foco o estado ecológico; b) estudo da estrutura das comunidades, através do uso de análise multivariável para decompor padrões espaciais e temporais e factores explicativos intrínsecos. Foi levada a cabo uma campanha de amostragem anual em seis locais distintos ao longo do rio. Foram usados protocolos e procedimentos padronizados na caracterização biótica e abiótica de cada estação de amostragem. Pontualmente (no espaço e no tempo), foram registados valores elevados de metais no sedimento e nutrientes (mormente fosfatos). Não obstante, a qualidade ecológica do rio foi globalmente boa, apesar de algumas flutuações nos factores abióticos. O uso de índices bióticos, incluindo o $IPtI_N$ – resultante de um exercício de intercalibração – revelou uma boa qualidade da água e um estado ecológico excelente. A análise multivariável confirmou que a comunidade de invertebrados bênticos foi bastante homogénea entre épocas do ano e entre estações de amostragem, com algumas excepções. Esta última abordagem permitiu explorar os padrões espaciais e temporais de forma mais detalhada do que os índices bióticos, bem como quantificar a influência dos factores ambientais subjacentes. Apesar da presença de algumas fontes de contaminação, os impactos sobre a comunidade de macroinvertebrados foram negligenciáveis. Em perspectiva, o Rio Mau é, afinal, bom.

keywords

Mau River, multiple stressors, ecological status, Water Framework Directive, benthic invertebrate community, water quality

abstract

Mau River suffers the influence of multiple stressors. Water pollution in this case is particularly worrying because Mau River is a tributary of Vouga River; both rivers are used for several activities, including the domestic consumption water in the latter. However, the presence of these factors alone does not guarantee a poor ecological status, as rivers have some self-depuration capacity. The main goal of the Water Framework Directive (WFD - Directive 2000/60/CE, 2000) is to attain or preserve good ecological quality in waterbodies in all EU Member States. Thus, assessing the ecological status of this river is necessary within the scope of WFD. Biomonitoring programs, recommended by WFD as part of the ecological assessment, rely on bioindicators, which are very useful in the study of the effects of stressors. Benthic macroinvertebrates have been widely used – and are strongly recommended – as biological indicators of water quality in river management. This work aimed to study the effects of multiple stressors (runoff from abandoned mines, domestic effluents and agriculture runoffs) on Mau River, by exploring the seasonal and spatial variation of its benthic macroinvertebrate communities. Two distinct approaches were followed: a) a water quality approach, using biotic indices and focusing on ecological status; b) a community structure approach, using multivariate analyses to decompose spatial and temporal patterns and underlying explanatory factors. A one-year sampling campaign was carried out at six distinct locations along the river continuum. Standard protocols and procedures were used in the abiotic and biotic characterisation of each sampling station. Sporadically (in space and in time), high levels of metals and nutrients (chiefly phosphates) were found in sediment and water samples, respectively. Nevertheless, the overall ecological quality of the river was good, despite some fluctuations in the abiotic framework. The use of biotic indices, including $IPtI_N$ – which resulted from an intercalibration exercise – revealed good water quality and a high ecological status. Multivariate analysis confirmed that the benthic invertebrate community is fairly homogeneous among seasons and among sites, with a few exceptions. The latter approach allowed exploring the spatial and seasonal patterns with finer resolution than biotic indices, as well as quantifying the underlying environmental explanatory factors. Despite the presence of some contamination sources, the impacts on the macroinvertebrate community were negligible. Putting it into perspective, Mau River (Bad River, from Portuguese) is, after all, a good one.

Índice

Introdução geral

Ao longo do último século, o rápido crescimento populacional e tudo o que ele implica (desenvolvimento industrial, expansão das áreas metropolitanas, necessidade crescente de alimentos e consequente aumento das áreas de culturas agrícolas) provocou um forte aumento da contaminação e poluição do meio ambiente, à escala global. O Homem tem reconhecido desde sempre como seu privilégio poluir o ambiente, seja ele aquático, aéreo ou terrestre. Poluição é um termo aplicado a qualquer estado ou manifestação ambiental que é prejudicial ou imprópria para a vida, resultando da falha em atingir ou manter o controlo sobre as consequências ou efeitos laterais químicos, físicos ou biológicos dos hábitos sociais, industriais e científicos do ser humano (Collocott & Dobson, 1974).

Os sistemas aquáticos são habitualmente afectados por múltiplos agentes de *stress*. As massas de água são frequentemente o receptáculo final dos contaminantes, sejam estes despejados na água ou no solo, uma vez que a água desempenha um papel importante no transporte ou evacuação de vários produtos. Algumas destas substâncias provêm de esgotos domésticos ou efluentes industriais e agrícolas (Mendes & Oliveira, 2004). Estas substâncias também se acumulam nos sedimentos das linhas de água (Förstner & Wittmann, 1979, Nascimento, 2003). A passagem e acumulação de contaminantes no compartimento aquático (coluna de água e sedimento) comprometem a qualidade geral da água e o estado ecológico do ecossistema.

Qualidade da água: perspectiva histórica

A água é essencial à sobrevivência do Homem e de todos os seres vivos, daí que a manutenção da sua boa qualidade seja fundamental. No passado, a avaliação desta qualidade era feita com base apenas na visão, sabor e olfacto dos examinadores (ver perspectiva histórica de Nunes, 2007). Com a evolução e introdução de novas técnicas de detecção, foram estabelecidos padrões de qualidade da água baseados na concentração de elementos ou compostos que nela poderiam estar presentes, de modo a ser compatível com a sua utilização para determinados fins (abastecimento público e industrial, preservação da vida aquática, irrigação, recreação, agricultura, navegação e paisagismo) (Tucci, 2002). Num contexto nacional, estes padrões estão definidos nos Decretos-Lei nº 236/98 de 1 de Agosto e 306/2007 de 27 de Agosto.

Esta visão antropocêntrica sobre a água fez com que, até aos finais do século XX, a legislação portuguesa, assim como a europeia, apenas exigisse que se fizessem análises físico-químicas (ou microbiológicas, em alguns casos restritos) à água para determinar a sua aptidão para os vários usos humanos (rega, aquacultura, consumo, etc.). No caso deste tipo de análise, o acompanhamento e vigilância são levados a cabo através da recolha periódica de amostras e análise posterior de uma variedade de parâmetros de carácter físico-químico. Contudo, esta caracterização do meio aquático é incompleta porque é pontual no espaço e no tempo. Muitas das descargas nos rios são intermitentes e produzem picos de concentração química ao longo do rio. Da mesma forma, a presença de um determinado poluente num curso de água indica uma descarga do mesmo a montante, mas não indica com precisão a sua fonte. Com a aprovação da Directiva nº2000/60/CE do Parlamento Europeu e do Conselho, de 23 de Outubro (Directiva Quadro da Água), transposta para a legislação nacional pela Lei da Água (Lei nº 58/2005 de 29 de Dezembro) e pelo Decreto-Lei nº77/2006 de 30 de Março, a monitorização dos ecossistemas aquáticos passou a reger-se por um novo paradigma, que abandona a abordagem clássica da água como recurso (perspectiva antropocêntrica), centrando-se agora na água como suporte de ecossistemas (perspectiva ecocêntrica) (INAG, 2008a).

A Directiva Quadro da Água (DQA) estabelece um quadro de acção comunitária no domínio da política da água e veio assim incumbir todos os Estados-Membros da União Europeia da protecção, melhoria e recuperação de todas as massas de água de superfície, com o objectivo final de alcançar um bom estado ecológico das mesmas. Para que tal seja possível, a DQA recomenda que seja feita uma monitorização das massas de água segundo parâmetros físico-químicos, hidromorfológicos e biológicos no sentido de determinar o estado ecológico das formações aquáticas relativas a situações de referência pré-estabelecidas. No caso dos rios e lagos, os descritores biológicos são as comunidades de fitoplâncton (só para os lagos), macrófitos, fitobentos (diatomáceas), macroinvertebrados bênticos, e fauna piscícola. Uma das razões para a exigência desta monitorização mais alargada deriva do facto de os métodos biológicos, os quais recorrem à utilização de bioindicadores, serem mais eficazes na obtenção de pistas sobre situações de poluição contínua e intermitente e integrar as variações ambientais (Nunes, 2007).

Biomonitorização e bioindicadores

Um bioindicador aplicado à avaliação da qualidade da água pode definir-se como sendo uma espécie (ou conjunto de espécies) que apresenta requisitos particulares em relação a uma ou a um conjunto de variáveis físicas ou químicas; deste modo, a sua presença ou ausência, bem como as alterações na abundância, morfologia ou comportamento revelam se as condicionantes ambientais consideradas se encontram ou não nos limites de tolerância dessa espécie em particular (Rosemberg & Resh, 1993). Deste modo, as comunidades de organismos sensíveis (que não suportam as novas condições impostas) comportam-se como intolerantes, verificando-se uma diminuição ou mesmo o desaparecimento dos seus efectivos. Pelo contrário, as comunidades de organismos tolerantes não sofrem variações significativas. Se a perturbação acarretar o desaparecimento dos intolerantes (por fuga ou morte), o espaço e recursos deixados disponíveis são ocupados por novas ou já existentes comunidades de organismos tolerantes. Deste modo, as variações na composição e estrutura das comunidades de organismos vivos dos rios podem interpretar-se como sinais evidentes de algum tipo de contaminação (Alba-Tercedor, 1996). Portanto, no contexto do desenvolvimento sustentável e conservação de ambientes aquáticos, os bioindicadores têm um papel importante na gestão adequada dos recursos (Gamboa et al., 2008). Em conjunto com informação físico-química recolhida na água, na atmosfera e no solo, eles permitem identificar, dentro de uma escala de qualidade, o nível de deterioração ambiental (Arenas, 1993). Considera-se por isso que um meio aquático apresenta uma boa qualidade ecológica (vide Directiva 2000/60/CE) quando tem características naturais que permitam que no seu leito se desenvolvam as comunidades de organismos que lhe são próprias (Alba-Tercedor, 1996).

A monitorização biológica (biomonitorização), através da utilização de bioindicadores, apresenta várias vantagens (comparativamente à monitorização química) (Pafkin et al., 1989):

- As comunidades biológicas reflectem a qualidade ecológica geral (i.e., integridade química, física e biológica), avaliando portanto o estado geral do sistema aquático.
- As comunidades biológicas integram os efeitos de diferentes agentes de *stress* proporcionando assim uma medida holística do seu impacto global. As comunidades também integram as variações ao longo do tempo (visão retrospectiva) e fornecem uma medida ecológica da flutuação das condições ambientais.
- A monitorização regular das comunidades biológicas é relativamente económica, particularmente quando comparada com a avaliação da toxicidade dos poluentes.
- No caso de não haver critérios para impactos ambientais específicos (ex: impactos sem fonte definível que degradam o ambiente), as comunidades ecológicas podem ser o único meio prático de avaliação.
- O estado das comunidades ecológicas é de interesse directo para o público como medida de um ambiente livre de poluição, ao passo que os resultados das monitorizações químicas não são tão bem compreendidos e relacionados com o estado do ambiente.

Tanto os métodos biológicos como os químicos desempenham um papel fundamental para o sucesso de um programa de controlo da poluição. Ambos devem ser considerados complementares em vez de mutuamente exclusivos (Pafkin et al., 1989). De acordo com as recomendações da DQA, só assim se obterá uma visão holística do estado ecológico dos locais, sobretudo quando se lida com uma contaminação ligeira.

Macroinvertebrados bênticos

De entre a grande variedade de organismos que podem ser usados como bioindicadores, os macroinvertebrados aquáticos ocupam um lugar de destaque.

As razões fundamentais para esta preferência baseiam-se nas várias características que estes organismos apresentam (Alba-Tercedor, 1996, Peralta, 2004, Hellawell, 1986, Cummings, 1992):

- Tamanho relativamente grande (>500 µm, visíveis a olho nu).
- Amplamente distribuídos e abundantes em ecossistemas aquáticos.
- Amostragem relativamente fácil, com técnicas padronizadas que não requerem um esforço de amostragem demasiado grande.
- Têm ciclos de desenvolvimento suficientemente grandes para que permaneçam nos cursos de água tempo suficiente para detectar qualquer alteração.
- Necessitam, depois de uma perturbação, de um tempo mínimo de recolonização de cerca de um mês e às vezes mais; por isso, os efeitos de uma perturbação podem detectar-se várias semanas e inclusive meses depois de esta ter ocorrido.
- A sua elevada diversidade e sensibilidade faz com que sejam bons indicadores da acção de variados tipos de contaminação.
- A resposta da maioria das espécies a diferentes tipos de poluição está bem estabelecida.
- Existem boas chaves de identificação taxonómica, pelo menos até à família.
- Existem vários métodos de análise desenvolvidos e difundidos, incluindo índices bióticos e de diversidade.

A comunidade de macroinvertebrados bênticos em locais isentos de poluição pode apresentar uma elevada biodiversidade, mas geralmente esta empobrece rapidamente quando o seu *habitat* se degrada (Peralta, 2004).

Metodologias de análise das comunidades de macroinvertebrados

O uso das comunidades de macroinvertebrados para estudar estas situações de poluição recorre a diversas metodologias disponíveis.

Uma dessas metodologias é o uso de índices de biodiversidade. Estes índices são expressões matemáticas que usam três componentes da estrutura de uma comunidade, nomeadamente riqueza (número de espécies presente), equitabilidade (uniformidade na distribuição dos indivíduos nas espécies) e abundância (número total de organismos presentes), para descrever a resposta de uma comunidade à qualidade do seu ambiente (Metcalfe-Smith, 1994). Segundo Neher *et al.* (1995) os índices de diversidade apresentam pouca ou nenhuma sensibilidade a mudanças na composição do *taxon*, embora se mostrem sensíveis ao declínio do seu número. Geralmente, ecossistemas pobres em espécies são considerados como tendo uma qualidade aquática degradada (Kenney et al., 2009). Gray e Delaney (2010) concluíram que os índices de diversidade medem o *stress* total e portanto são melhores que os índices bióticos na detecção da existência de impacto causado por escorrências mineiras ácidas nos rios, mas baseiam-se num modelo teórico de comunidade não totalmente apropriado para estudar os efeitos deste agente de *stress*.

Os índices bióticos também são usados frequentemente em estudos com macroinvertebrados. Estes costumam ser específicos para um tipo de alteração ou contaminação e/ou região geográfica, e baseiam-se no conceito de organismo indicador. Eles permitem uma aferição do estado ecológico de um ecossistema aquático afectado por um qualquer processo de contaminação (Gamboa et al., 2008). São especialmente eficazes na avaliação dos efeitos causados por poluição orgânica; a sua aplicação a outros tipos de poluição ou perturbação pode ser questionável (Metcalfe-Smith, 1994). No início, desenvolveram-se índices bióticos para os quais era necessária uma identificação taxonómica dos macroinvertebrados ao nível do género ou espécie (Róldan, 2003), ou uma estimativa quantitativa das abundâncias (Alonso & Camargo, 2005); todavia, comprovou-se que os índices mais práticos (pela sua facilidade de obtenção) são aqueles em que só são necessários dados qualitativos (presença–ausência) e uma identificação taxonómica até ao nível da família (Leiva, 2004). Deste modo, uma amostragem exaustiva pode garantir a colheita dos *taxa* presentes na área de estudo (Alba-Tercedor, 1996) e aumentar a fiabilidade do índice aplicado. Muitos índices têm sido desenvolvidos mas todos assentam em duas premissas básicas. Primeiro, os diferentes *taxa* bioindicadores variam na sua tolerância à poluição. A sua presença ou ausência pode ser usada para estimar o grau de poluição especialmente se houver um *ranking* de resposta conhecido para os *taxa* tolerantes e sensíveis. Segundo, o número de indivíduos presentes varia com a intensidade da poluição, e a abundância também pode ser incorporada num índice biótico (Jeffries & Mills, 1996).

A análise multivariável dos dados também é usada com frequência para analisar comunidades de macroinvertebrados. Este tipo de análise estuda toda a comunidade, incorporando processos naturais e parâmetros indicadores da presença de poluição (Jeffries & Mills, 1996). A principal vantagem deste tipo de análise é a integração de dados multidimensionais com o mínimo possível de perda de informação, permitindo a detecção de tendências de variabilidade pouco evidentes nos dados (Rosemberg & Resh, 1993). Ela detecta também padrões sazonais e espaciais da comunidade.

Num estudo de biodiversidade, o ideal será fazer uma utilização conjunta de várias métricas de análise das comunidades de macroinvertebrados e conjugá-las com a análise dos descritores físico-químicos. Desta forma será possível obter uma visão abrangente dos efeitos dos vários impactos sofridos por determinada comunidade de macroinvertebrados.

Objectivos e estrutura da dissertação

Este trabalho teve como objectivo avaliar a qualidade ecológica do Rio Mau (Sever do Vouga), no âmbito da DQA, e poderá constituir uma base para trabalhos futuros. Para fazer esta avaliação ecológica, estudou-se de que forma os múltiplos agentes de *stress* que exercem influência sobre o Rio Mau afectam a estrutura das comunidades de macroinvertebrados bênticos nele presentes. A conceptualização teórica e os objectivos específicos do trabalho, assim como as metodologias usadas, os resultados obtidos e a sua discussão são apresentados numa secção própria e independente, constituindo o Capítulo 1 da presente dissertação. Este capítulo é precedido da presente introdução geral, onde a temática da dissertação é inicialmente abordada e enquadrada, e o objectivo geral do trabalho é definido.

Capítulo 1

«Water quality and benthic invertebrate community structure in Mau River (Sever do Vouga, Portugal)»

Introduction

The main goal of the Water Framework Directive (WFD - Directive 2000/60/CE, 2000) is to attain or preserve good ecological quality in waterbodies in all EU Member States, or at least prevent further deterioration of surface and groundwater. In order to accomplish this, Member States have the obligation of assessing the ecological status of their waterbodies, through the monitoring of phytoplankton, phytobenthos, macrophytes, benthic invertebrates, and fish assemblages. This way, WFD abandons the classic approach of the water as just a resource (anthropocentric perspective) and instead sees it as ecosystem holder (ecocentric perspective) (INAG, 2008a).

Mau River, a small mountain river in central Portugal, is located far from large industrial and housing areas. This could lead us to expect good ecological status, as it seems to suffer few impacts. However, as most rivers and waterbodies (see Ormerod et al., 2010 and references therein), it suffers the influence of multiple stressors (a stressor is a variable that potentially provokes a measurable biological or ecological response (Statzner & Beche, 2010)). Mau River potentially suffers impacts from organic and inorganic pollution from abandoned mines, agriculture and sewage, either on specific locations (near the dumping places) or along the river continuum. This water pollution is particularly worrying because Mau River is a tributary of Vouga River and both rivers are used for fishing and recreational activities (picnic areas, river beaches). Furthermore, water is captured in Vouga River for human consumption, downstream its confluence with Mau River.

The wastes from mining activity, containing high metal concentrations, represent a source of metal contamination for a long time following extraction (Kelly, 1988, Ferreira da Silva et al., 2009), as in the case of Malhada and Braçal mines in Mau River. In these mines, prospection of lead and zinc took place for more than one century until the 1950s, when they were deactivated. The effects of mine drainage can be summarized as acidity, metal toxicity, metal precipitation and salinization (Gray, 1997, Gray & Delaney, 2010). Mau River also crosses a small locality (Silva Escura), where agriculture practices contribute with fertilizer and pesticide inputs. The most common agriculture contaminants in the hydrographic basin of Caima and Mau Rivers are phosphates, nitrates and pesticides, which may be composed by metals like Cd, Cu, Pb, As, Zn and Fe (Nunes, 2007). Thus, agriculture can influence biological quality of the water by interfering in the nutrient cycles. Besides this, cesspools (individual and collective) are still common in Silva Escura, also exerting a potentially negative influence on the ecological quality of Mau River.

However, the presence of these factors alone does not guarantee a poor ecological status. Loredo et al. (2010) reached the conclusion that mine drainage and spoil heap leaches show occasionally very acidic conditions, but these conditions are easily neutralised when polluted waters reach streams or rivers with enough water flow to dilute the concentration of pollutants. Their work also showed that, in spite of the past extensive mining activities in Los Rueldos and the weathering of mine wastes, local streams were not significantly polluted. Even in the case of severe impacts, it is possible that parts of a stream or river can recover without mitigation measures. This was observed by Cerqueira et al. (2008) in Antuã River where, despite the relevance of pollution problems, considerable water quality improvement was observed in the final stretch of the river, giving evidence of a great self-depuration capacity.

Assessing the ecological status of this river is necessary within the scope of WFD. For example, this could lead to the outline of a mitigation plan for this river, if necessary. Biomonitoring programs, recommended by WFD as part of the ecological assessment, rely on bioindicators. A bioindicator can be defined as a species (or group of species) which present specific requests concerning one or more physical or chemical variables, in a way that changes in presence or absence, number, morphology or behaviour of that species indicate that the abiotic variables are in their tolerance limits (Rosemberg & Resh, 1993). Bioindicators are very effective in obtaining clues about situations of continuous and intermittent pollution (Nunes, 2007) and they integrate the effects of multiple stressors. Benthic macroinvertebrates have been widely used – and are strongly recommended – as biological indicators of water quality in river management (Barbour et al., 1999, Cummings, 1992, INAG, 2008a, Klemm et al., 2002, Tachet et al., 1980, Metcalfe-Smith, 1994).

This work aimed to study the potential effects of multiple stressors (acid mine drainage, domestic effluents and agriculture activities) on Mau River, by accompanying the seasonal and spatial variation of its benthic macroinvertebrate communities. Two distinct approaches were followed: a) a water quality approach, using biotic indices and focusing on ecological status; b) a community structure approach, using multivariate analyses to decompose spatial and temporal patterns and underlying explanatory factors.

Materials and Methods

Study area and sampling stations

This work focused on Mau River, which presents Braçal and Malhada mines in its catchment basin, and is located in the vicinities of Sever do Vouga (40º44'00''N 8º22'00''W) – see Figure 1. The main extraction in Braçal and Malhada mines was galena ore (native lead sulphide), with more accidental extraction of zinc blende ore and iron pirite ore (Cabral et al., 1889). The distance between the old mines is less than 1 km. Mau River has an extension of 12.4 km, beginning in Serra do Salgueiro until Pessegueiro do Vouga, where it meets Vouga River. The constant occurrence of rocky outcrops makes the water to flow through a sinuous path creating some waterfalls which oxygenate the water.

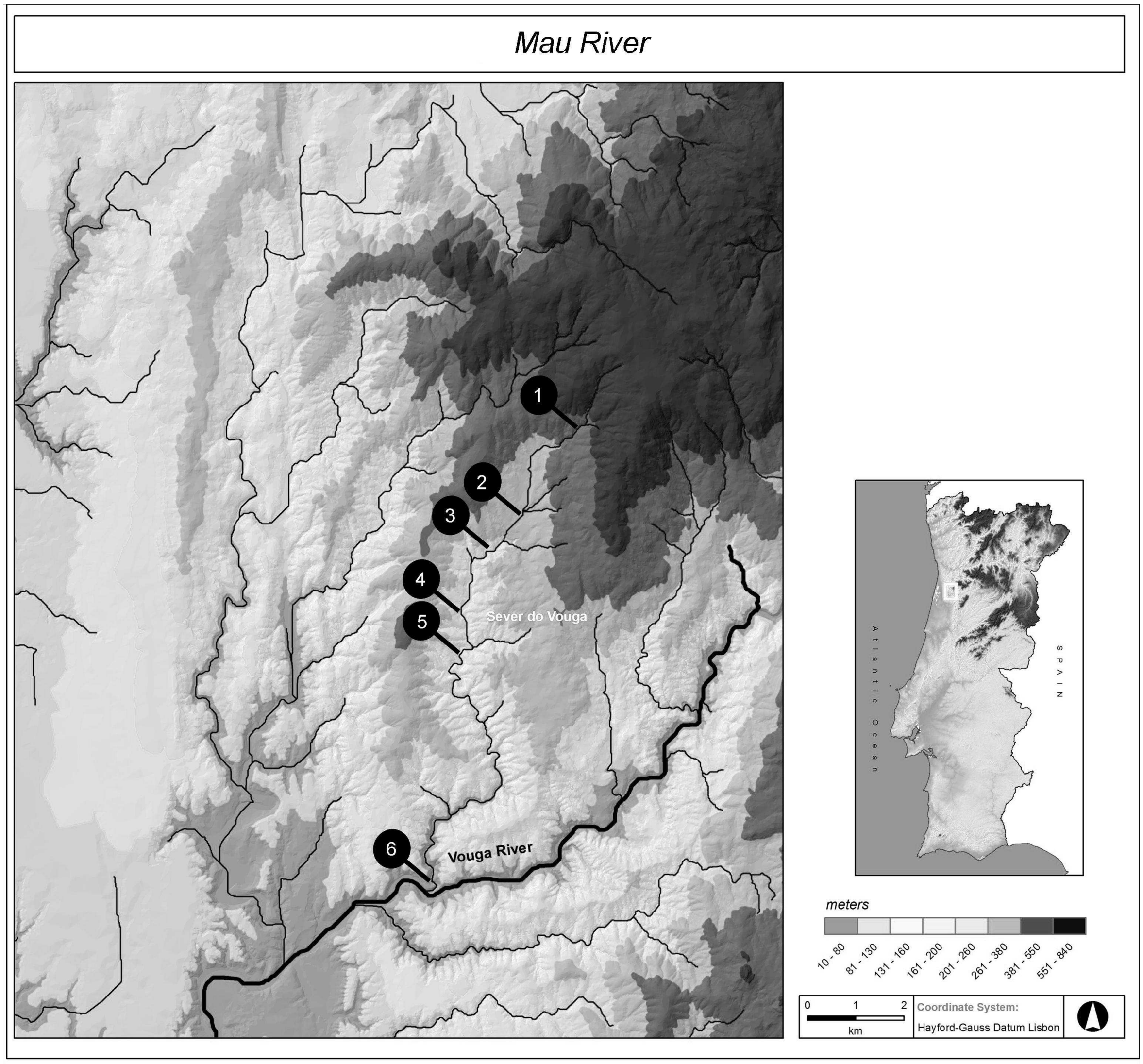

Figure 1 – Map of the study area (Mau River) with localisation of sampling stations.

Figure 1 shows the localisation of sampling stations. Station 1 was located near the river headwater, with reduced human impact. Mau River then crosses a small rural village, Silva Escura, suffering some contamination from domestic sewage and agricultural activities. Station 2 was located at this point. Station 3 was located further downstream, after a 25 m high waterfall; a recreational park exists in the surroundings of the river at this site. Stations 4 and 5 were the closest ones to Malhada and Braçal mines, respectively. They were both located downstream of each mine. Station 6 was close to the river mouth.

Riparian vegetation along the river extension is usually tall and dense, with plants belonging to different families, namely Commelinaceae, Umbelliferae, Compositae.

Sampling strategy and methods

There were 4 sampling campaigns, which took place in May 2005 (spring), August 2005 (summer), November 2005 (autumn) and February 2006 (winter). In all campaigns, all 6 stations (see above) were characterised as described below.

At each station, chemical and physical parameters were measured *in situ* using portable testing meters: pH (pH 330 from WTW, Germany), temperature and conductivity (LF 330 from WTW), and dissolved oxygen (Oxi 315i from WTW). A 1.5 L water sample was collected in plastic bottles for posterior determination of other parameters (see Laboratory analysis). The section of the river-bed and water depth were also measured. Water transparency was classified by observation. Sediment samples were collected from the river-bed at each station into plastic bags. They were maintained and transported at 4ºC in the dark, and later frozen at -20ºC until further analysis.

Benthic macroinvertebrates were collected at each station by kick-sampling, using a standard hand net (500 µm pore size; square frame, 0.33 x 0.33 m). To assure similar effort among sites and seasons, sampling was performed during 3 min, along 3-4 transects covering the diversity of habitats (margins, aquatic macrophytes, riffles, main canal) and sediment types (rocks, gravel, sand, etc.). Following collection, samples were fixed with 4% buffered formalin.

Laboratory analysis

Water samples were filtered through standard glass fiber filters (GF/C type, pore 1.2 µm); filtrate was used for nutrient analysis and residue was used to quantify total suspended solids (TSS). Nutrients were analysed following the Hach test methods for the determination of nitrites (NO_2^-), nitrates (NO_3^-), ammonia (NH_4^+), orthophosphates (PO_4^{3-}) and sulphates (SO_4^{2-}) in water samples. All analyses followed widely disseminated protocols (A.P.H.A. et al., 1998).

Metal analysis was performed for sediment samples. Metal extraction was performed by mixing them with distilled water in a proportion of 1:2 (w/v). They were left overnight in an orbital shaker at 200 rpm. On the day after, elutriates were centrifuged for 15 min at 4000 rpm and the supernatant was filtered by a 45 µm pore filter. Afterwards, the filtrate was acidified to pH<2 with nitric acid 65 %. Metal concentrations were then determined by inductively coupled plasma mass spectrometry (ICP-MS) for Al, As, B, Ba, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Sr, V and Zn.

At the laboratory, preserved benthic macroinvertebrate samples were washed through a 500 µm sieve and organisms were sorted out. After this, they were stored in 70 % alcohol and identified to the lowest practical taxonomical level, generally the family (or genus, when possible) using standard keys (Serra et al., 2009, Tachet et al., 1980, Macan, 1959, Sundermann et al., 2007, Richoux, 1982, Pattée & Gourbault, 1981, Elliott, 1977).

Data analysis: abiotic variables

Physical and chemical parameters and sediment metal concentrations were analysed using a 2-way ANOVA without replication to explore differences among sampling sites and among sampling seasons. A significance level (α) of 0.05 was used. Additionally, principal components analysis (PCA) was used to explore patterns in the environmental data matrix; physical and chemical parameters and sediment metal concentrations were analysed individually. PCA is an ordination technique usually employed in the analysis of multivariate matrices of abiotic data, since it assumes an underlying linear mathematical model (ter Braak, 1995, Gauch, 1982). Before running the analysis, the environmental data were standardized by subtracting the mean from each observation and dividing by the corresponding standard deviation.

Data analysis: water quality approach

Macroinvertebrate data was analysed using some metrics, including *taxa* richness, number of families, Shannon's diversity index (H'), Pielou's equitability index (J'), EPT (Ephemeroptera-Plecoptera-Trichoptera) index, biological water quality indices IBMWP (Iberian Biological Monitoring Working Party) (Alba-

Tercedor & Sánchez-Ortega, 1988, Alba-Tercedor et al., 2002, Jáimez-Cuéllar et al., 2002) (Table 1) and IASPT (Iberian Average Score per *Taxon*) (Rodriguez & Wright, 1987).

Table 1 – Water quality and ecological status classes according to IBMWP (Jáimez-Cuéllar et al., 2002)

IBMWP	Water Quality	Ecological status
>100	Good. Waters without contamination or with very subtle contamination.	High
61 – 100	Acceptable. Some water contamination effects are evident.	Good
36 – 60	Doubtful. Contaminated waters.	Moderate
16 – 35	Critical. Very contaminated waters.	Poor
<15	Very critical. Heavily contaminated waters.	Bad

North Invertebrate Portuguese Index ($IPtI_N$) was calculated using the recommendations given by INAG (2009). This metric resulted from the European and Portuguese intercalibration exercises (INAG, 2009, Buffagni & Furse, 2006, Buffagni et al., 2006) and is defined in the European Commission's Decision 2008/915/CE. It is the weighted sum of some metrics, each normalized using the quotient between the obtained values and corresponding reference values for small dimension rivers of northern Portugal, category which Mau River belongs to (INAG, 2008b).

$$\mathbf{IPtI_N} = (0{,}25 \times \mathbf{S}) + (0{,}15 \times \mathbf{EPT}) + (0{,}1 \times \mathbf{J'}) + (0{,}3 \times (\mathbf{IASPT} - 2)) + (0{,}2 \times \mathbf{log\ (Sel.\ ETD + 1)}),$$

where **S** stands for richness; **EPT** is the number of families belonging to orders Ephemeroptera, Plecoptera, Trichoptera; **J'** is Pielou's equitability index (**J'** = H'/ln(S), with H' being Shannon's diversity index); **IASPT** results from the quotient between IBMWP and the number of families with IBMWP scores in the sample; and **log (Sel. ETD + 1)** stands for the logarithm of the sum of abundances of organisms belonging to families Heptageniidae, Ephemeridae, Brachycentridae, Goeridae, Odontoceridae, Limnephilidae, Polycentropodidae, Athericidae, Dixidae, Dolichopodidae, Empididae, Stratiomyidae (ETD *taxa*).

The final $IPtI_N$ value is itself subjected to normalization, by dividing it by the corresponding reference value for small dimension rivers of northern Portugal (1.02, as in INAG, 2009). In this way, the final result can be expressed in Ecological Quality Ratios (EQR), which are associated with different categories of ecological quality; frontier values to classify small dimension rivers of northern Portugal are presented in Table 2.

Table 2 – Water ecological status according to EQR of $IPtI_N$ (INAG, 2009).

Tipology	EQR ($IPtI_N$)	Ecological status
Small Dimension Rivers of Northern Portugal (N1 ≤ 100 km^2)	>0.87	High
	0.86 – 0.65	Good
	0.64 – 0.44	Moderate
	0.43 – 0.22	Poor
	< 0.22	Bad

Selected metrics were analysed using a 2-way ANOVA without replication (using SPSS®) to explore differences among sampling sites and among sampling seasons. A significance level (α) of 0.05 was used.

Data analysis: community structure approach

Benthic invertebrate abundance data were compiled as a multivariate matrix. Detrended Correspondence Analysis (DCA) was used to analyse gradients in community structure, including spatial and temporal patterns. DCA is an improved eigenvector ordination technique based on reciprocal (weighted) averaging, and is commonly used in community ecology, as it assumes an underlying unimodal mathematical model (ter Braak, 1995, Gauch, 1982). Abundances were log-transformed prior to analysis. Downweighting of rare species was used, and species and sample scores were plotted in a bidimensional space.

Additionally, redundancy analysis (RDA) was also used to explore seasonal and spatial gradients in the benthic invertebrate assemblage. RDA is a canonical ordination technique which constrains the biotic data matrix relatively to the environmental gradients (ter Braak, 1995). As a consequence, it extracts synthetic gradients from the biotic and environmental matrices, which are quantitatively represented by arrows in graphical biplots (ter Braak, 1995). The length of the arrow is relative to the importance of the explanatory variable in the ordination, and arrow direction indicates positive or negative correlations. RDA is the extension of PCA (unconstrained form) in the same way as canonical correspondence analysis (CCA) is the extension of weighted averaging or (detrended) correspondence analysis (CA or DCA). Ideally, CCA should be used with species abundance data sets (ter Braak, 1995); however, ter Braak and Smilauer (1998) recommend the use of RDA when the environmental gradient is not very pronounced (given by a length of gradient of the first axis of DCA run on the biotic matrix lower than 4 SD).

Five distinct RDA models were built from the benthic invertebrate data set: 1) sediment metal concentrations as explanatory variables (M); 2) water physical and chemical parameters as explanatory variables (PC); 3) global model (M+PC); 4) M partialling out PC (as covariable; see ter Braak & Verdonschot, 1995); 5) PC partialling out M (as covariable). A forward selection procedure (ter Braak & Verdonschot, 1995) was performed *a priori* on the sediment metal concentration and physical and chemical data sets, in order to include only significant explanatory variables in the model (significance was tested using a Monte Carlo permutation test; α=0.05). Similarly to DCA, downweighting of rare species was employed in all analyses. Monte Carlo permutation tests were used to assess the significance of the relation between macroinvertebrate data and explanatory variables for each of the above models. The variation partitioning technique proposed by Borcard et al. (1992) was used to quantify the variation explained by each of the environmental subsets of explanatory variables (see also Okland & Eilersten, 1994). To do so, we compared the resulting percentage of variance of the partial RDAs (as the quotient between the sum of canonical eigenvalues and total inertia) with that of the global model.

All multivariate analyses were performed using CANOCO software.

Results

Abiotic framework

Mau River fluctuated in terms of pH, while exhibiting low nutrient concentrations, reduced conductivity and reduced TSS (except in February at the most upstream stations). Dissolved oxygen was equal to or above saturation. These conditions suggest a river in good condition (Table 3). Overall, Mau River was fairly homogeneous among sampling stations. With the exception of conductivity and width, no significant differences were found among sites for physical and chemical parameters (Table 4). Differences in conductivity reflect the upstream-downstream gradient, with minima in station 1 and maxima in station 6 (Table 3). The width of the canal varied between 1.8 m in station 1 and 7.7 m in station 5. Seasonality was observed for pH, dissolved oxygen, temperature, conductivity, depth, TSS, nitrates, phosphates, and sulfates (see Table 3), since significant differences were found among sampling seasons (Table 4). The only exceptions were width, ammonia, and nitrites, which showed no significant seasonal fluctuations.

The PCA diagram revealed a large scatter of sampling stations (Figure 2), as a consequence of seasonal variations of the river physico-chemistry (see above). A noticeable exception was site 1 (S1), whose PCA scores were all distributed in the bottom left part of the biplot, associating this site with low conductivity, low concentration of sulfates, high amount of suspended solids (TSS) and high dissolved oxygen levels. Still, most sites were located in the middle region of the diagram, corroborating the among site homogeneity shown above. Stations 5 and 6, in November, formed a distinct cluster, as a result of high phosphate, nitrite and ammonia levels.

Table 3 – Range (min.-max.) of physical and chemical parameters measured at Mau River between May 2005 and February 2006.

	Sampling station					
Parameter	**1**	**2**	**3**	**4**	**5**	**6**
pH	5.65-8.65	5.91-7.40	5.99-7.83	6.68-7.57	6.85-7.85	6.74-7.61
O_2 (mg L^{-1})	8.4-12.4	8.5-13.1	9.1-18.4	11.1-18.4	8.6-13.7	11.2-11.7
Temperature (ºC)	9.4-14.5	10.8-16.3	10.7-16.3	10.1-16.7	9.5-16.5	9.1-18.0
Conductivity (µS cm^{-1})	23.8-33.2	49.0-64.6	44.6-71.1	49.8-77.8	55.2-66.7	58.3-77.3
Section width (m)	1.0-2.5	1.5-5.3	3.3-5.7	3.7-5.4	4.9-9.5	3.6-4.0
Water depth (m)	0.20-0.40	0.20-0.30	0.20-0.40	0.10-0.40	0.15-0.30	0.10-0.30
TSS (mg L^{-1})	1.34-54.95	2.28-41.24	2.60-5.97	1.38-6.13	0.48-9.89	1.24-4.37
Ammonia (mg L^{-1})	0.00-0.01	0	0.00-0.01	0.00-0.19	0.00-0.28	0.00-0.04
Nitrates (mg L^{-1})	0.07-0.30	0.07-1.20	0.08-1.60	0.08-1.30	0.08-1.40	0.09-1.40
Nitrites (mg L^{-1})	0.00-0.01	0.00-0.01	0.00-0.01	0.00-0.01	0.00-0.01	0.00-0.03
Phosphates (mg L^{-1})	0.12-0.14	0.12-0.37	0.11-0.40	0.15-0.65	0.09-1.06	0.12-0.94
Sulfates (mg L^{-1})	0.00-6.00	1.00-7.00	0.00-7.00	1.00-12.00	0.00-9.00	6.00-10.00
Transparency	clear	clear	clear	clear	clear	clear

Table 4 – Source of variation, degrees of freedom (df), mean square and p values of 2-way ANOVA without replication applied to several physical and chemical parameters measured in Mau River.

Parameter	Source of variation	df	Mean Square	p
pH	Site	5	0.100	0.758
	Season	3	2.21	**<0.001**
	Residual	15	0.192	
O_2	Site	5	5.00	0.197
	Season	3	25.0	**0.002**
	Residual	15	2.96	
Temperature	Site	5	1.07	0.067
	Season	3	51.6	**<0.001**
	Residual	15	0.407	
Conductivity	Site	5	664	**<0.001**
	Season	3	277	**0.002**
	Residual	14	31.9	
Width	Site	5	14.3	**0.001**
	Season	3	1.54	0.448
	Residual	15	1.65	
Depth	Site	5	0.00300	0.668
	Season	3	0.0290	**0.005**
	Residual	15	0.00400	
TSS	Site	5	136	0.378
	Season	3	458	**0.031**
	Residual	15	118	
Ammonia	Site	5	0.00400	0.554
	Season	3	0.00300	0.582
	Residual	15	0.00500	
Nitrate	Site	5	0.191	0.060
	Season	3	2.13	**<0.001**
	Residual	15	0.0700	
Nitrite	Site	5	3.40×10^{-5}	0.728
	Season	3	3.80×10^{-5}	0.615
	Residual	15	6.10×10^{-5}	
Phosphate	Site	5	0.0420	0.307
	Season	3	0.286	**0.001**
	Residual	15	0.0320	
Sulfate	Site	5	23.4	0.060
	Season	3	29.5	**0.044**
	Residual	15	8.55	

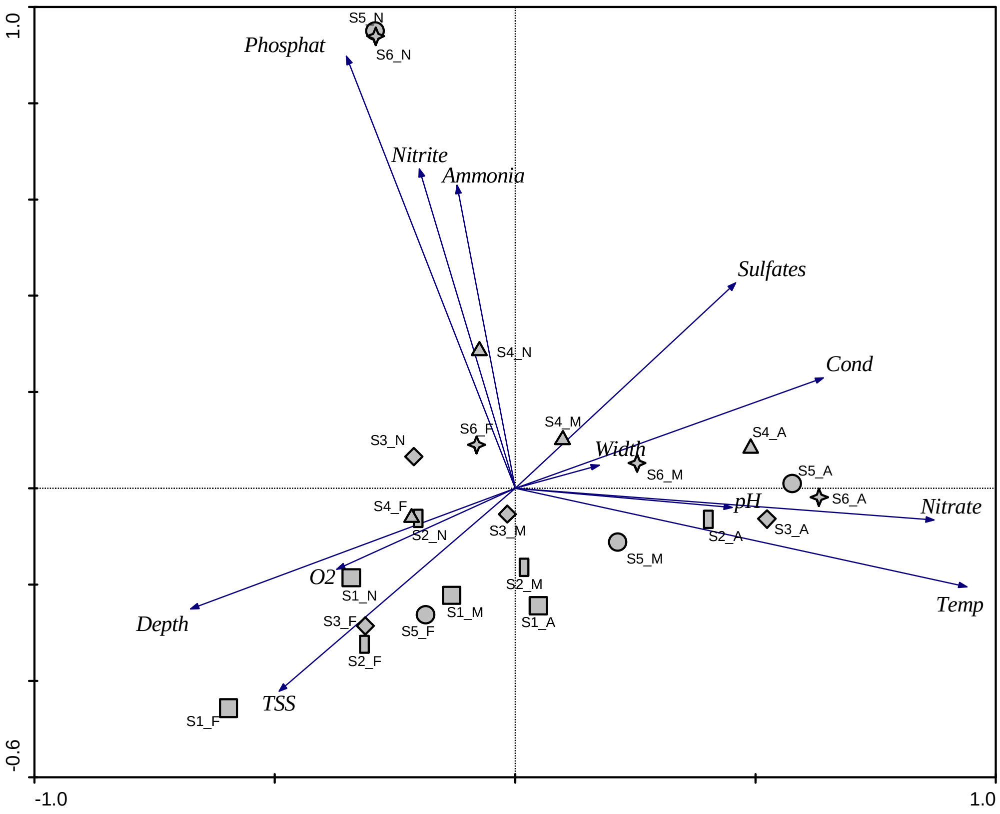

Figure 2 – PCA biplot of physical and chemical parameters (represented by arrows) and sample scores. Phosphat stands for phosphates, Cond stands for conductivity, Temp stands for temperature and TSS stands for total suspended solids. Sampling stations are represented by an S followed by the site number (1-6) and a letter representing the month of data collection (M for May, A for August, N for November, F for February); example: S2_M stands for site 2 in May. Eigenvalues are 0.293 and 0.183, respectively for axes 1 and 2.

Low levels of V, Cr, Ni, Cu, As, Sr and Cd were found in sediments. On the contrary, high levels of Al and Fe were found at all combinations of stations versus sampling season. B, Mn, Zn, Ba and Pb were found at intermediate levels, as shown in Table 5. No significant differences were found among sites for all metals (Table 6). Some elements (Al, Cr, Mn, Fe, Ni, Zn, As, Sr and Ba) were found to vary among seasons, as demonstrated by the presence of a significant effect of season in the analyses of variance. No consistent pattern was found among these metals, although there was a tendency for higher concentrations during the dry period (especially August) and lower concentrations in February. In fact, the most worrying Fe and Al concentrations in sediments were recorded in August (Table 5).

Similarly to physical and chemical parameters, the PCA scores for sampling stations seem more dependent on seasonality than on a spatial gradient (Figure 3). This is perceptible in the biplot in an apparent gradient from February (bottom left) to May (top left); November and August samples occupy an intermediate position. This gradient is associated with Ni and Sr, which increase from February to May, and B, which decreases from February to May (see Figure 3 and Table 5). Also, seasonality is evident in August samples, which occupy a position on the right side of the diagram as a consequence of very high levels of Fe, Al and Pb (see Figure 3 and Table 5). This is especially noticeable for site 4 (S4).

Table 5 – Range (min.-max.) of sediment metal concentrations ($\mu g\ Kg^{-1}$) measured at Mau River between May 2005 and February 2006.

	Sampling station					
Metal	**1**	**2**	**3**	**4**	**5**	**6**
B	<20-482	<20-410	275-1134	103-1216	150-998	41-587
Al	456-22926	75.9-16410	589-40434	610-78200	1218-27574	397-5712
V	1.36-25.1	<2-7.20	0.954-57.6	1.44-118	<2-5.80	<2-5.13
Cr	0.862-21.0	<2-4.80	0.544-39.8	0.960-90.2	2.00-32.0	<2-3.42
Mn	59.3-288	22.6-143	85.4-306	33.2-875	32.5-646	40.0-153
Fe	296-17502	38.4-13940	488-35402	888-75716	1942-35480	674-7864
Ni	<20	<20	<20	<20	<20	<20
Cu	2.06-22.2	<20	2.11-27.8	<20	<20	<20
Zn	5.61-400	<4-377	13.4-316	46.9-546	62.7-344	103-171
As	0.400-3.92	1.65-3.84	1.38-11.6	1-30.8	2.23-17.5	1.38-4.60
Sr	7.10-46	13.5-83.1	8.03-72.0	14.4-52.0	10.2-56.0	4.28-62.0
Cd	<2	<2	<2	<2	0.12-10.6	<2
Ba	11.9-714	27.3-868	12.0-896	14.1-1310	55.2-818	65.3-628
Pb	1.77-21.7	<20-860	8.35-128	64.0-2596	147-2566	5.40-842

Table 6 – Source of variation, degrees of freedom (df), mean square and p values of 2-way ANOVA without replication of sediment metal concentrations from Mau River.

Parameter	Source of variation	df	Mean Square	p
B	Site	5	7.13×10^4	0.662
	Season	3	1.36×10^5	0.325
	Residual	15	1.09×10^5	
Al	Site	5	1.63×10^8	0.472
	Season	3	1.33×10^9	**0.002**
	Residual	15	1.69×10^8	
V	Site	5	558	0.464
	Season	3	1.37×10^3	0.109
	Residual	15	571	
Cr	Site	5	289	0.441
	Season	3	1.19×10^3	**0.024**
	Residual	15	283	
Mn	Site	5	7.53×10^4	0.086
	Season	3	1.06×10^5	**0.046**
	Residual	15	3.13×10^4	
Fe	Site	5	1.59×10^8	0.436
	Season	3	1.25×10^9	**0.002**
	Residual	15	1.54×10^8	
Ni	Site	5	9.63	0.377
	Season	3	151	**<0.001**
	Residual	15	8.36	
Cu	Site	5	87.9	0.287
	Season	3	11.9	0.904
	Residual	15	63.8	
Zn	Site	5	6.87×10^3	0.786
	Season	3	6.96×10^4	**0.015**
	Residual	15	1.43×10^4	
As	Site	5	34.7	0.365
	Season	3	131	**0.020**
	Residual	15	29.5	
Sr	Site	5	404	0.231
	Season	3	1.92×10^3	**0.003**
	Residual	15	260	
Cd	Site	5	5.14	0.404
	Season	3	3.30	0.566
	Residual	15	4.70	
Ba	Site	5	5.19×10^4	0.441
	Season	3	6.21×10^5	**<0.001**
	Residual	15	5.10×10^4	
Pb	Site	5	4.99×10^5	0.352
	Season	3	1.13×10^6	0.080
	Residual	15	4.12×10^5	

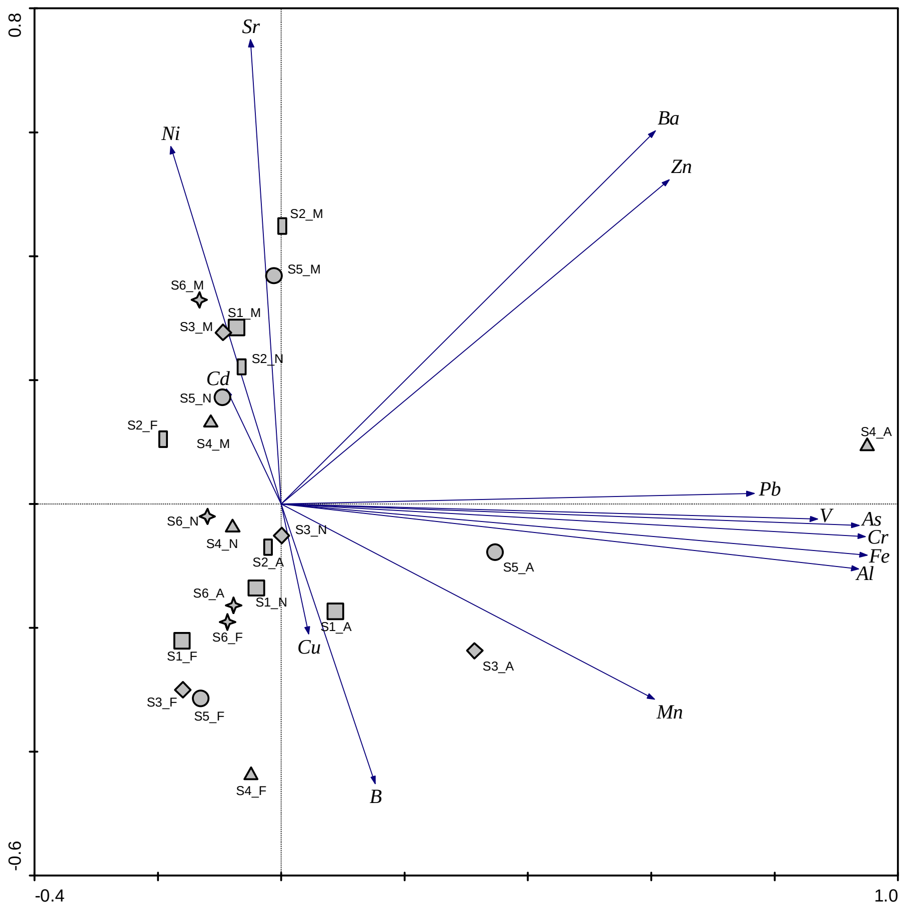

Figure 3 – PCA biplot of sediment metal concentrations (represented by arrows) and sample scores. Sampling stations are represented by an S followed by the site number (1-6) and a letter representing the month of data collection (M for May, A for August, N for November, F for February); example: S2_M stands for site 2 in May. Eigenvalues are 0.466 and 0.148, respectively for axes 1 and 2.

Benthic invertebrates – water quality approach

A total number of 30,477 individuals were identified. They were distributed by 70 different *taxa*. Overall, specific richness was high, as well as the total number of families, which was almost always above the reference value (30) for small dimension rivers of northern Portugal. The only exceptions occurred at stations 1 and 5 in August (Figure 4), which constituted the lowest values of both richness and number of families. The benthic macroinvertebrate assemblage registered maximum values of richness (family and number of *taxa*) at station 2 in every season, except winter (February), when the maximum total number of *taxa* was registered at station 6. These fluctuations among sites and among seasons were statistically significant (Table 7).

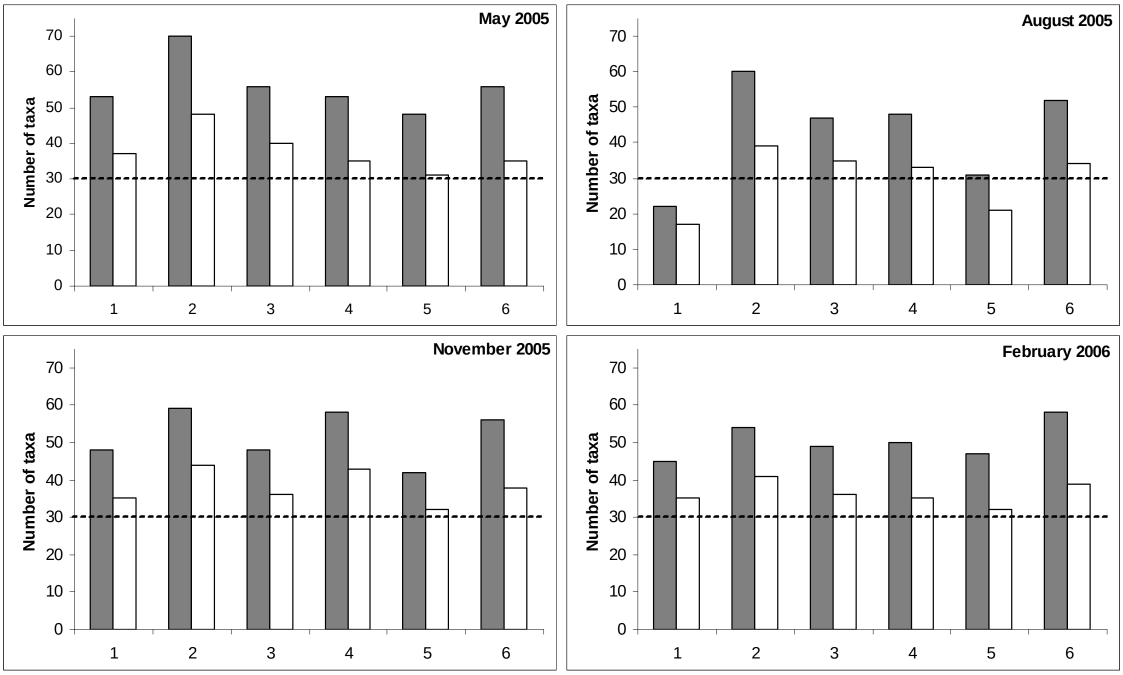

Figure 4– Specific richness (grey bars) and number of families (white bars) for each sampling station in each season. The dashed line marks the reference value for number of families according to INAG (2009).

Table 7 – Source of variation, degrees of freedom (df), mean square and p values of 2-way ANOVA without replication applied to several metrics derived from the macroinvertebrate data matrix.

Parameter	Source of variation	df	Mean Square	p
Families	Site	5	87.5	**0.002**
	Season	3	97.8	**0.007**
	Residual	15	15.0	
Richness	Site	5	167	**0.002**
	Season	3	222	**0.014**
	Residual	15	33.9	
Diversity	Site	5	0.330	0.512
	Season	3	0.133	0.129
	Residual	15	0.149	
Equitability	Site	5	0.0150	0.368
	Season	3	0.0110	0.254
	Residual	15	0.0100	
EPT	Site	5	8.89	0.065
	Season	3	22.1	0.392
	Residual	15	8.32	
IBMWP	Site	5	2.06×10^3	**0.018**
	Season	3	2.82×10^3	0.070
	Residual	15	715	
IASPT	Site	5	0.418	0.511
	Season	3	0.152	0.103
	Residual	15	0.170	
$IPtI_N$	Site	5	0.0230	0.121
	Season	3	0.0210	0.117
	Residual	15	0.0100	

Shannon's diversity index (H') and Pielou's equitability index (J') were both high for all sampling stations in all seasons. As for richness, their lowest values were recorded at station 1 in August. Despite these fluctuations, differences among sites and seasons were not significant (Table 7). Equitability's values were always close and sometimes higher than the reference value (0.71) for small dimension rivers of northern Portugal (Figure 5). Sites 2 and 6 were exceptions to this, since equitability was lower than the reference value with some consistency.

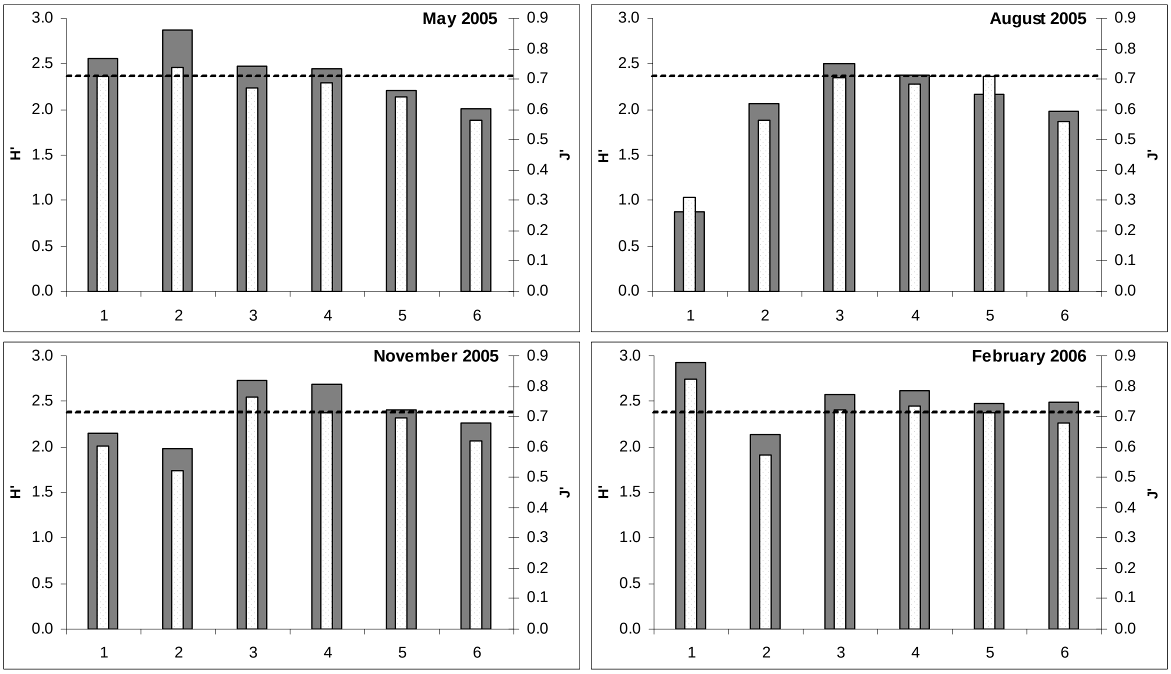

Figure 5 – Diversity (H', grey bars) and equitability (J', white bars) for each sampling station in each sampling period. The dashed line marks the reference value for equitability according to INAG (2009).

EPT *taxa* were present in all sampling stations. In most of them, the values were close to or above the reference value for small dimension rivers of northern Portugal. The most noticeable exceptions were station 1 and 5 in August (Figure 6), following the same pattern as for richness. In fact, station 5 almost always recorded the lowest EPT value. Still, no significant differences were found between sites or seasons (Table 7), although in the former case the p-value was marginal.

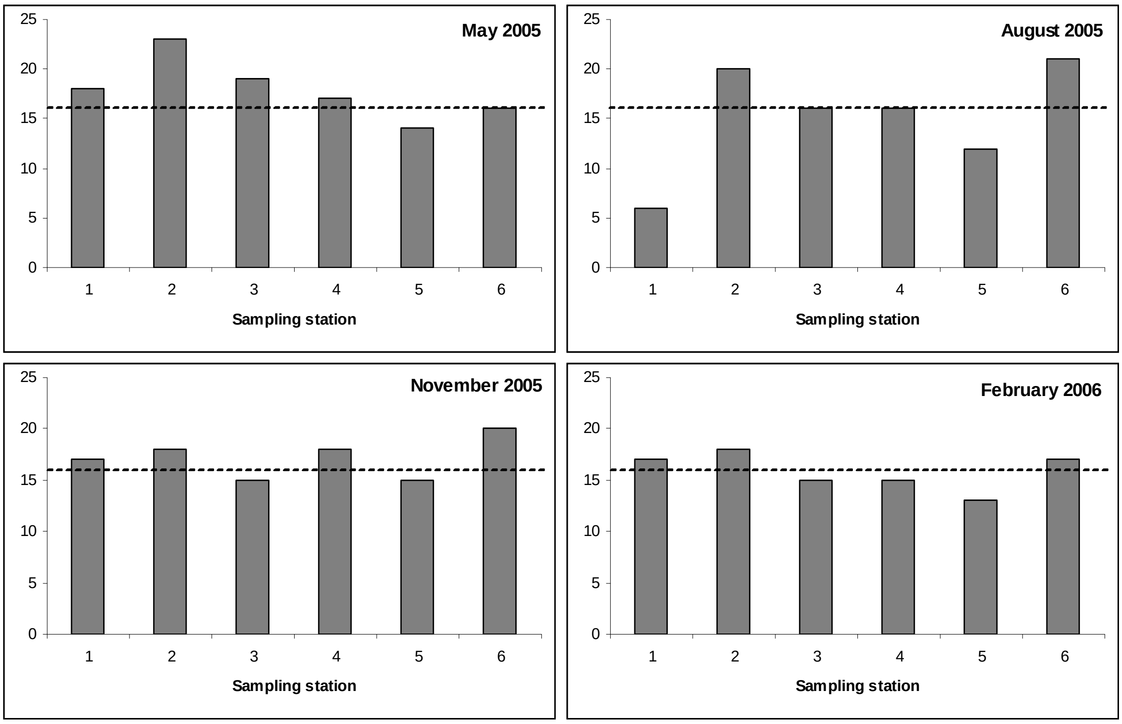

Figure 6 – EPT *taxa* for each sampling station in each season. The dashed line marks the reference value for EPT *taxa*, according to INAG (2009).

Very high IBMWP values were found in all stations and seasons (Figure 7). Still, along with richness and number of families, IBMWP registered significant differences among sites (Table 7). This is probably due to station 5, where this index was consistently lower than the remaining sites. Also noticeable, and confirming a tendency already observed previously, is a drastic reduction in the IBMWP in station 1 in August. This was reflected in the water quality status (good), which in all other sites was considered to be high, regardless of the season.

IASPT recorded small oscillations among stations and seasons, which were found to be non significant (Table 7). Globally, all registered values were slightly lower than the reference value (6.52) for small dimension rivers of northern Portugal. The only exceptions were stations 5 and 6 in August and 4 in May (Figure 7).

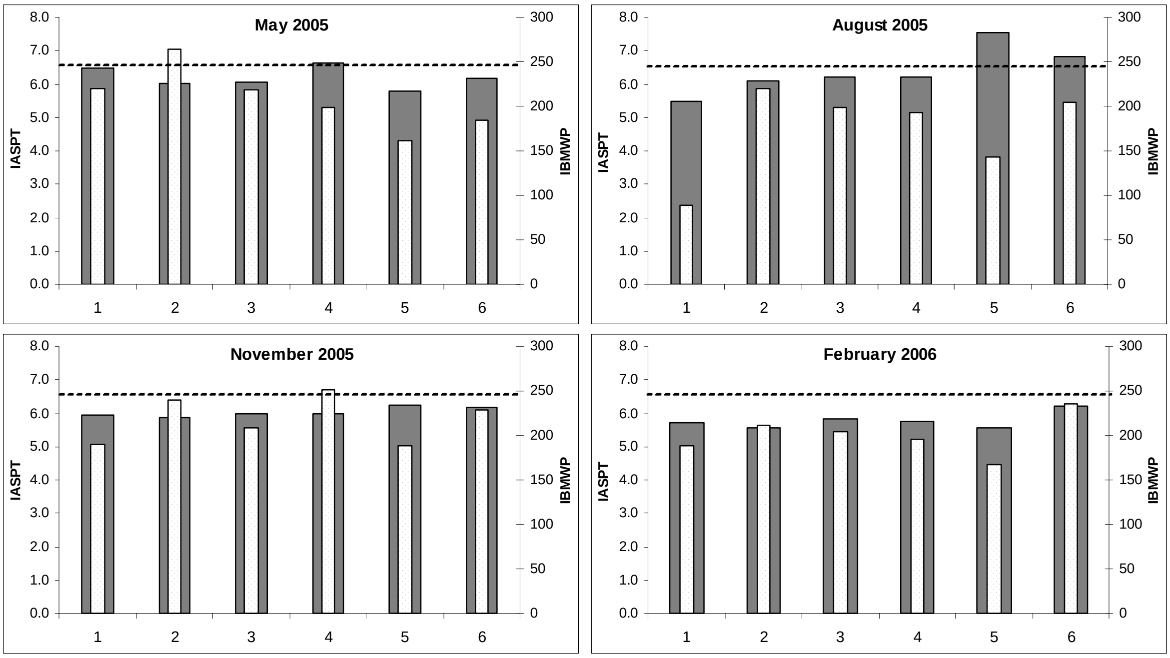

Figure 7 – IASPT (grey bars) and IBMWP (white bars) for each sampling station in each season. The dashed line marks the reference value for IASPT, according to INAG (2009).

No significant differences were found among sites and among seasons for $IPtI_N$ (Table 7). Concordantly, water quality based on $IPtI_N$-derived EQR values was almost always high (Table 8). Exceptions are once again station 1 in August, with moderate water quality, and station 5 in February, with good water quality. In fact, the lowest value of $IPtI_N$ was recorded at station 1 in August.

Table 8 – Ecological status of each sampling station in all four seasons according to $IPtI_N$ and respective EQR.

Season	Sampling station	IPtIN	EQR	Ecological status
May 2005	1	1.043	1.023	High
	2	1.21	1.186	High
	3	1.07	1.049	High
	4	1.059	1.038	High
	5	0.936	0.917	High
	6	0.976	0.957	High
August 2005	1	0.554	0.543	Moderate
	2	1.041	1.021	High
	3	0.972	0.953	High
	4	0.997	0.977	High
	5	0.892	0.874	High
	6	1.087	1.065	High
November 2005	1	0.988	0.969	High
	2	1.04	1.02	High
	3	1.018	0.998	High
	4	1.118	1.096	High
	5	1.017	0.997	High
	6	1.091	1.07	High
February 2005	1	0.95	0.932	High
	2	0.967	0.948	High
	3	0.946	0.928	High
	4	0.994	0.975	High
	5	0.869	0.852	Good
	6	1.037	1.017	High

Benthic invertebrates – community structure approach

The length of gradient of the first axis (2.108) of the DCA revealed a modest gradient in *taxa* succession. Consequently, a homogeneous distribution of the sampling stations was observed (Figure 8). Station 1, however, is in the periphery of the main cluster (see magnified zone – Figure 8). Correspondingly, *taxa* that only occur at this site are located in the bottom right quadrant (e.g. *Sialis*, Chloroperlidae). Several of these exclusive *taxa* occur only occasionally and at low abundances: e.g. *Dicranota*, *Riolus* (adults), *Helodes* (larvae) and *Chelifera* in November; Nemouridae Athericidae, *Helophorus* (adults), Dytiscidae (adults) and *Aselus* in May; Lymnaeidae and *Mesovelia* in August (Figure 9). It therefore appears that these rare *taxa* are responsible for the peripheral scores of station 1. Nevertheless, their position in the DCA diagram is still fairly close to the other sites.

Other *taxa* can be found in the periphery of the central cluster (Figure 9); however, they mainly constitute taxonomical entities that sporadically occur in sites by seasons combinations. Indeed, the overall distribution of sample scores revealed a considerable similarity between sampling stations (with the exceptions highlighted above), as the result of sharing numerous *taxa* (which are present in a large cluster in the centre of DCA diagram – Figure 9).

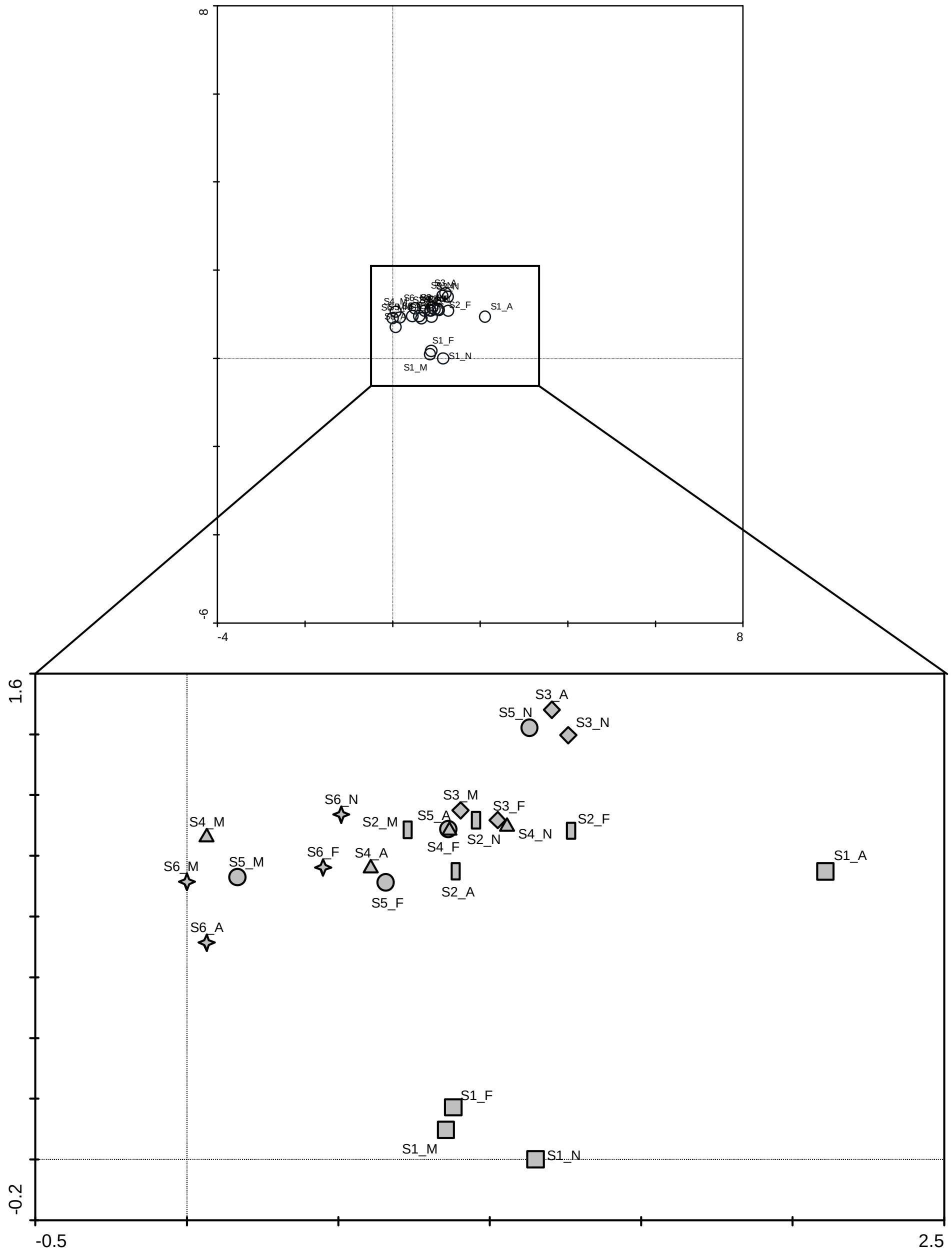

Figure 8 – Sample scores for DCA on benthic invertebrate abundances. Bottom panel zooms in an amplified region of the top panel to improve visualization. Sampling stations are represented by an S followed by the site number and a letter representing the month of data collection (M for May, A for August, N for November, F for February); example: S2_M stands for site 2 in May. Eigenvalues are 0.165 and 0.117 for axes 1 and 2, respectively.

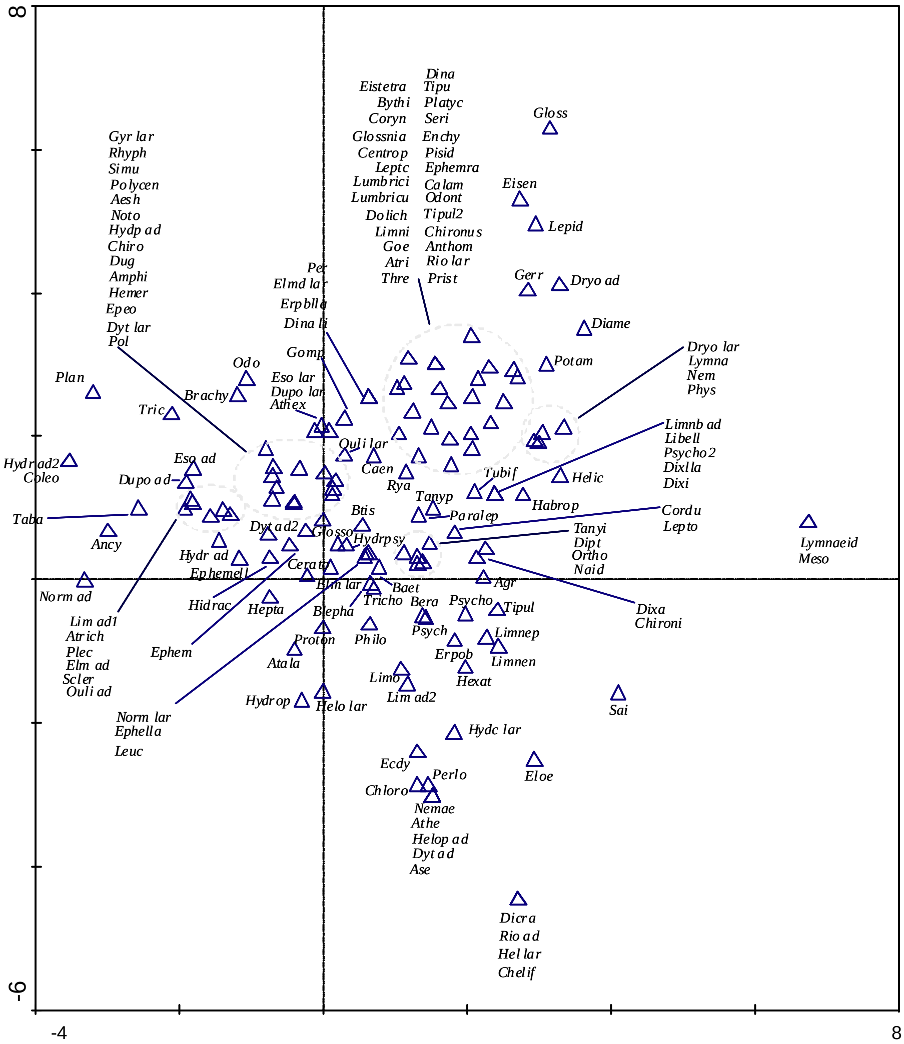

Figure 9 – DCA diagram of macroinvertebrate species scores. Grey circles do not aim to define groups; they were used to simplify the labelling. *Taxa* abbreviations are in Annex (Tables A.9-A.12). Eigenvalues are 0.165 and 0.117 for axes 1 and 2, respectively.

The RDA global model integrated the benthic invertebrate data with extracted gradients from significant (forward selection procedure using Monte Carlo permutation tests, $p \leq 0.05$) physical and chemical parameters (temperature, conductivity, nitrates and phosphates) and metal concentrations (Ni and Ba) (Figure 10). The resulting diagram suggests a separation of samples in two main groups: one of the groups is constituted by all the samples from November and February – the wet seasons (dashed line circle); the other group is constituted by almost all the samples from May and August – the dry seasons (solid line circle).

This is consistent with the distribution of species scores (Figure 11), which show that *taxa* with higher abundances in November and February occur mostly in the top right quadrant. Complementarily, *taxa* that were more abundant in May and August are consistently found in the bottom left quadrant. Lumbriculidae, *Paraleptophlebia*, Psychomiidae, *Agrion* and *Potamopyrgus antipodarum*, constitute good examples of the first cluster (*taxa* associated with wet seasons). *Hydrocyphon* (larvae) is an example of *taxa* occurring only in November and February in Mau River. Tanypodinae, Leuctridae, Ephemeroptera, *Oulimnius* (adults), *Dupophilus* (adults) and *Elmis* (adults) are some examples of *taxa* associated with dry seasons. Some *taxa* are exclusively found during this period, such as *Habrophlebia*.

These seasonal differences in the abundance of benthic invertebrates are responsible for the separation of the two clusters. RDA also allows identifying the environmental gradients which explain the distribution of *taxa* (Figure 10). The dry season group was associated with increasing values of temperature, metals (Ni and Ba) and nitrates. In opposition, the wet period cluster is mostly associated with lower values of these variables. Station 1 (especially in August) was located far from the other sample scores, as previously found in PCA and DCA diagrams.

Beyond the separation of the two clusters, a spatial pattern is apparent during the wet season that is not perceptible in May and August samples. Thus, samples belonging to this group form a slight gradient from the most upstream (bottom right) to the most downstream sampling stations (top left). The position of the most upstream sites corresponded to lower values of phosphates and conductivity, whereas the final portion of the gradient (the most downstream stations) was associated to higher values of phosphates and conductivity (Figure 10).

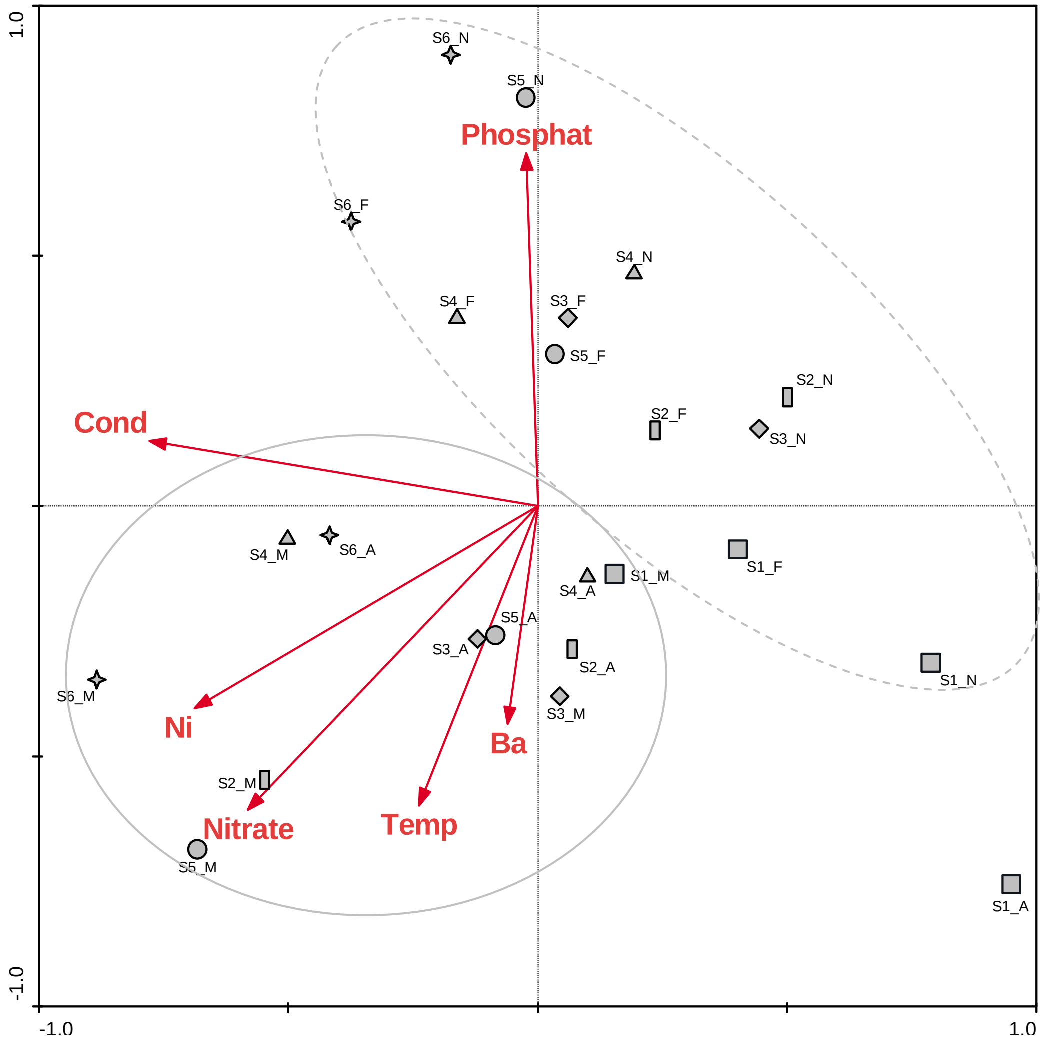

Figure 10 – Sample scores and environmental gradients (represented by arrows) of RDA on the benthic invertebrate data matrix. Phosphat stands for phosphates and Cond stands for conductivity. Sampling stations are represented by an S followed by the site number and a letter representing the month of data collection (M for May, A for August, N for November, F for February); example: S2_M stands for site 2 in May. Eigenvalues are 0.148 and 0.117 for axes 1 and 2, respectively.

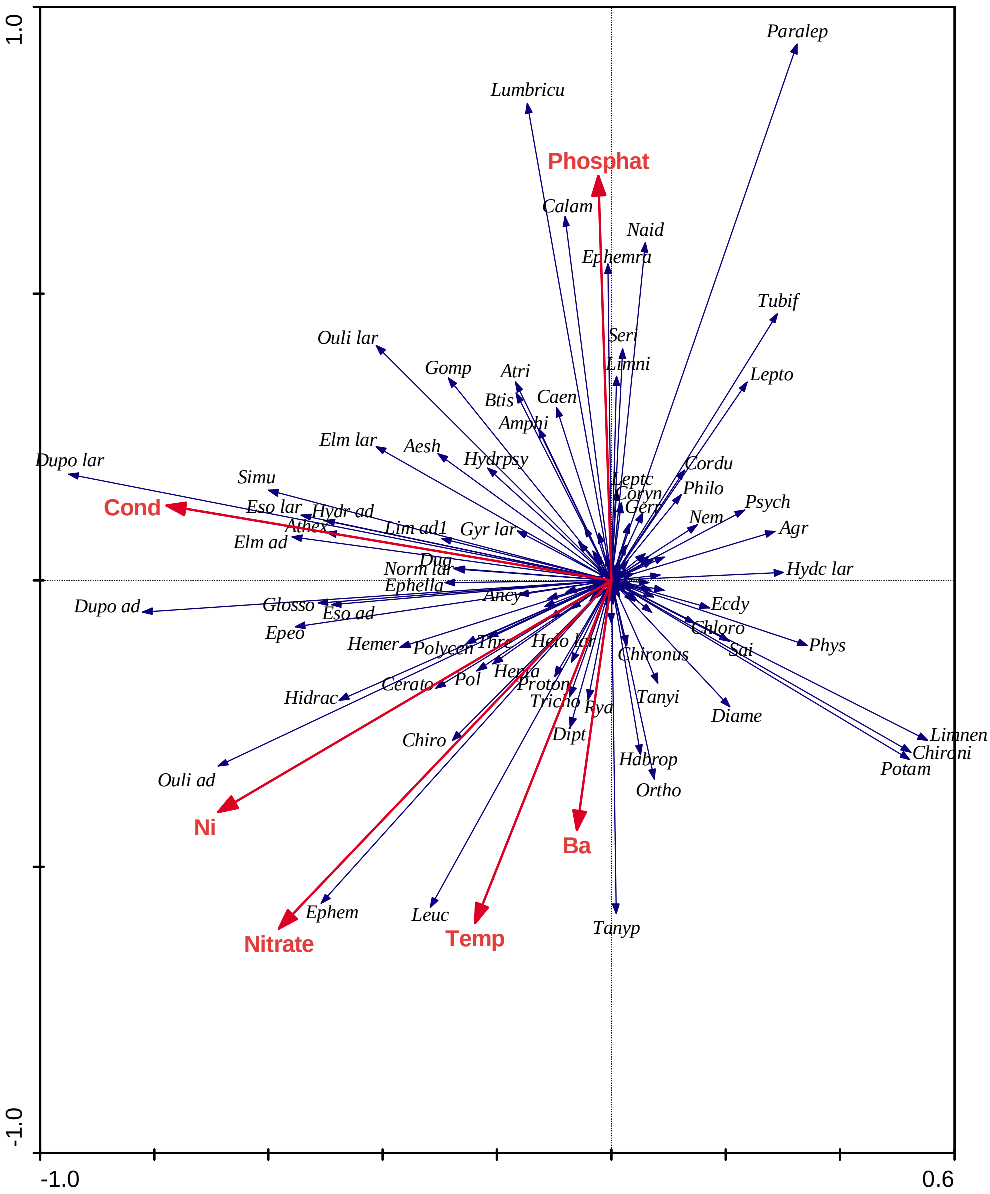

Figure 11 – Species scores (represented by black arrows) and environmental gradients (represented by grey arrows) of RDA on the benthic invertebrate data matrix. Species close to the origin were removed for visualization purposes. Phosphat stands for phosphates and Cond stands for conductivity. Sampling stations are represented by an S followed by the site number and a letter representing the month of data collection (M for May, A for August, N for November, F for February); example: S2_M stands for site 2 in May. Eigenvalues are 0.148 and 0.117 for axes 1 and 2, respectively.

Variation partitioning of the benthic invertebrate data set (Figure 12) allowed further enlightening of the percentage of explanation given by the abiotic variables (physical and chemical subset – PC – and sediment metal concentrations subset – M). The global RDA model (PC+M) explained 40.8 % of the total variation (a total of canonical eigenvalues of 0.408 in a possible total of 1.000); therefore, 59.2 % of the variation could not be explained by the studied abiotic variables. The RDA model for PC alone explained 32.7 % (sum of canonical eigenvalues=0.327) and the RDA model for M alone explained 16.7% (sum of canonical eigenvalues=0.167). Two additional models, partialling out each environmental subset at a time, allowed the quantification of “pure” PC variation (24.1 %; sum of canonical eigenvalues=0.241) and “pure” M variation (8.1 %; sum of canonical eigenvalues=0.081). Therefore, 8.6 % of the variation was explained by the intersection of PC and M (Figure 12). All RDA models were significant (Monte Carlo permutation tests, p≤0.05) except the constrained model with metal concentrations as explanatory variables and physical and chemical parameters as covariables (“pure” M).

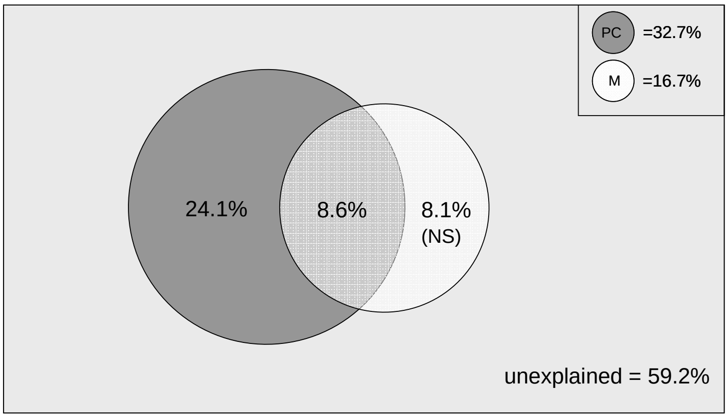

Figure 12 – Venn diagram showing the variation partitioning of the benthic invertebrate data set, which is explained by two different subsets of abiotic variables with Redundancy Analysis (RDA): physical and chemical parameters (PC) and sediment metal concentrations (M). The global RDA model (PC+M) explains 40.8% of total variation.

Discussion

Mau River was expected to suffer the effects of multiple stressors (abandoned mine drainage, agricultural activities and domestic sewage), either on specific locations or along its extension. However, the river was fairly homogeneous among sampling stations and presented high water quality. Most of the variation in its physico-chemistry and macroinvertebrate assemblage was due to seasonality. The good condition of the river contradicts expected impacts of multiple stressors and endorses the idea that this river suffers minor effects from recent and historical pollution.

Minima and maxima values of physical and chemical parameters were more or less consistently reached in the same months for all sampling sites (see Table A.1 to A.4 in the Annex). This marked seasonality was expected, as most of these parameters depend directly (temperature influences many of them) or indirectly on the season (e.g. TSS, solids are dragged into the river in larger quantities by more abundant rainfall in February). Conductivity was also affected by seasonal changes, which are a consequence of variations in the concentration of dissolved solids due to the seasonal fluctuations in the amount of water drained by the hydrologic system (Cerqueira et al., 2008). Local variation (upstream-downstream conductivity gradient) was also observed and was also expected, as upstream waters tend to have lower ionic concentrations because they usually are less polluted; these concentrations tend to increase along the extension of the water course.

Stations 5 and 6 in November seem to be in some way influenced by hydrologic drainage containing detergents (which usually contain phosphates) and sewage, as these sites are associated with higher concentrations of phosphates, nitrites and ammonia than the other sites. Still, ammonia values are not very high (Gago & Mana, 2007), even in wet season (November and February). Although phosphate levels are high, their impact on macroinvertebrate communities was only slight, as biotic indices for station 5 were depressed but were not markedly lower than most stations; station 6 communities do not seem to be affected by this high values of phosphates. Differences between stations 5 and 6 can not be explained on the basis of phosphates level alone, which may suggest the influence of other factors (station 5 is located in the vicinity of Braçal mine). Sewage impact was indeed expected for station 2 (located among the housing areas), but the analysis does not reflect that. However, Simuliidae was generally more abundant in this site (see Table A.9 to A.12 in the Annex), and this *taxon* is positively influenced by organic enrichment (Wright & Burgin, 2009), thus indicating a subtle impact in the macroinvertebrate community. The dominance of this *taxon* in station 2 was already reported in a previous study (in 1999-2000; unpublished data from our team).

No significant differences among sites were found for sediment metal concentrations, thus confirming the spatial homogeneity of the river and an unexpected lack of influence from Malhada and Braçal mines. We were expecting the existence of runoffs or drainage from the abandoned mines, leading to higher metal concentrations at these sites, which could alter macroinvertebrate abundance and biomass and reduce taxonomic diversity, as shown in other studies (e.g. Malmqvist & Hoffsten, 1999). Ephemeroptera and Plecoptera are considered to be generally sensitive to heavy metals, whereas Trichoptera are relatively tolerant (Malmqvist & Hoffsten, 1999, Hickey & Golding, 2002). Both sensitive and tolerant *taxa* were present in all sampling stations, with high levels of diversity and equitability. These results were corroborated by the variation partitioning of the benthic invertebrate data set, which showed that metals explain a small and non-significant percentage (8.1 %) of the total variation. However, interactive effects (explaining 8.6 % of total variation) between metals and other physical and chemical parameters were evident in the seasonal differences within the river. During low-flow conditions, mine drainage is the least diluted (Besser & Leib, 1999), as well as the receiving stream itself. This may have happened in August (higher levels of some metals characteristic to Malhada and Braçal mines – Pb, Fe) due to warmer temperatures and the reduced rainfall of 2005 (Cerqueira et al., 2008). Contrarily, the lowest metal concentrations were found in February (wet season), where rainfall leads to a more abundant water flow and turbulence, which may resuspend and drag contaminated sediments downstream. Riverbeds are transitional environments between groundwater and surface water and are both a sink and source of fine organic and inorganic sediment and associated pollutants (Jarvie et al., 2005). Still, bioavailability of metals is affected by numerous factors (e.g. pH, water hardness, and dissolved organic matter) which may modify toxicity in situ (Hickey & Golding, 2002). Indeed, our study does not allow us to infer about negative influence of metals on macroinvertebrate community, even during the dry period, when metal concentrations were higher.

Despite this evident seasonality in the variation of physical and chemical parameters and metal concentrations, macroinvertebrate assemblages did not seem to be strongly affected by seasons. The exceptions were the number of families and richness, which were affected by both seasonal and local variation. In natural stream systems, both living and detrital food bases are processed continuously, but there is a seasonal shift in the relative importance of autotrophic production *versus* detritus loading and processing (Vannote et al., 1980), which influence macroinvertebrates in a way that could lead to seasonal differences in biotic indices. Many headwater streams are strongly influenced by the riparian vegetation, which reduces autotrophic production by shading and contributes with large amounts of allochthonous detritus (Vannote et al., 1980). In some way, seasonal variations in Mau River could be explained by this factor, because of natural fluctuations in the presence and quantity of these materials, depending on the season, which probably affects invertebrates. Studies on headwater streams (see Vannote et al., 1980 and references therein) have shown that biological communities in most habitats can be characterized as forming a temporal sequence of synchronized species replacement. This could explain the seasonal variations in number of families and richness and the lack of variation in diversity and equitability. However, concerning the other biotic indices, these seasonal fluctuations did not seem to be well marked in Mau River.

Habitat features are very important for the distribution of macroinvertebrates (Lake, 2000) and streams of lower order may have localized effects of varying magnitude depending upon the volume and nature of the inputs (Vannote et al., 1980). Riparian vegetation was relatively dense at stations 3, 4, 5 and 6, increasing the particle loading to the stream waters, which could be responsible for the dominance of collector invertebrates, according to Whiles and Dodds (2002). Chironomidae, Ephemerellidae, Elmidae, Baetidae, Hydropsychidae, Simuliidae, Leptophlebiidae, Glossosomatidae and Lumbriculidae are some of these dominant collectors (Barbour et al., 1999) at these stations, repeating what was verified in a previous study (unpublished data from our team). Despite the river uniformity along the year, RDA put in evidence that there was a separation of two main groups, according to the macroinvertebrate community structure: dry season samples and wet season samples. In the latter season, there was a slight gradient along the river, indicating the progressive replacement of species. However, such a spatial segregation was not visible in the dry season, when metal concentrations were highest, especially in station 4. This confirms that metals are not affecting community structure and suggests that organic enrichment (mainly phosphorus) may cause spatial heterogeneity. However, it is unclear whether these changes were due to natural (see above) or anthropogenic influences.

There are no specific indicator species for acid mine drainage in affected rivers, although oligochaetes and dipterans, and chironomids in particular, are generally the dominant macroinvertebrate groups found downstream of mine drainage; on the contrary, ephemeropterans are particularly sensitive to it and are among the last group to recolonize rivers after contamination (Gray, 1997). Leptophlebiidae has reputation of being one of the most pollution-sensitive macroinvertebrate families worldwide (Malmqvist & Hoffsten, 1999, Wright & Burgin, 2009, Hickey & Golding, 2002). Mayfly (Ephemeroptera) abundance would generally provide a sensitive measure of the impact of metals on stream communities (Hickey & Golding, 2002). In Mau River, Leptophlebiidae are abundant, especially in the wet season, suggesting that Mau River has low pollution levels. This is supported by the presence in both seasons and most sites of other *taxa* recognized as the most sensitive to pollution, such as Chloroperlidae and Leuctridae (Plecoptera), *Paraleptophlebia* and *Habrophlebia* (Ephemeroptera) and Psychomiidae (Trichoptera). For example, Friberg et al. (2010) confirmed that *Leuctra* (Leuctridae) is highly sensitive and a good indicator organism of organic pollution. Hickey and Golding (2002) found that *Potamopyrgus antipodarum* is markedly more sensitive to chronic metal exposures than would be expected based on laboratory acute and chronic data. Like Leptophlebiidae, this *taxon* is also present in Mau River in high abundances in the wet season. In fact, site 5 (located downstream Braçal mine) is the only sampling station with consistently lower EPT *taxa*, probably due to the presence of a slightly higher concentration of metals, although they do not interfere very much in the survivorship of these invertebrates, keeping the index values above or very near the reference values in most cases.

The general lack of local variation corroborates the idea given by physical and chemical parameters and macroinvertebrate community that Mau River is in good ecological condition, being the observed variations due to the variability provoked by the natural succession of seasons that affect temperature, conductivity, phosphates, nitrates, and concentrations of Ni and Ba (variables chosen by multivariate analysis as significant). Apparently, stations 1 and 5 are the most different from all the others, although this was obvious only in August, when, of all 24 samples, station 5 scored the second lowest values in richness, number of families, EPT *taxa* and IBMWP and station 1 scored the lowest values for all the indices. According to $IPtI_N$, site 1 in August and site 5 in February are exceptions to the overall high ecological status, having moderate and good status, respectively. These differences were also reflected in the multivariate analysis, when station 1 samples emerged consistently apart from the cluster formed by all the other samples and invertebrate *taxa* associated with these locations were also shown in the periphery of the main cluster. The fact that multiple stressors can act synergistically has been experimentally demonstrated by some authors (Folt et al., 1999, Matthaei et al., 2006) and is evident in this work too. The differences in stations 1 and 5 are probably due to location and natural seasonal variations. Site 1 is the most upstream sampling station, with expected lower anthropogenic impact. However, there is an inhabited house nearby and riparian vegetation is occasionally cut to ease passage to upstream, so there may be more anthropogenic influence than expected for a headwater, leading to a moderate water quality in August, the worst recorded. It is possible that this result was due to a localized occasional event with human origin (as in the other seasons water quality was good and indices values were similar to the other sites) or it could be a natural reaction to differences in the presence or absence of leaves and other organic materials. Recent studies (e.g. Feld & Hering, 2007) have identified, using various multivariate approaches, that macroinvertebrates respond to combinations of natural environmental factors and anthropogenic pressures.

Mau River was considered to be homogeneous and have a good water quality, although there may be impacts from the multiple stressors affecting the river. This was verified both with the biotic indices and community structure approaches, which allowed to identify localized (in space and in time) impacts on the macroinvertebrate assemblage. Although useful and recommended within the WFD scope, the use of biotic indices was not as discriminating as the community structure analysis. The latter approach explored spatial and temporal trends with finer resolution, allowing a more detailed analysis of the species succession and quantifying the underlying environmental explanatory factors. Still, both approaches reveal that impacts are negligible at the Mau River scale, although contamination occurs at least sporadically. However, the fate of diffuse pollutants entering rivers depends not only on landscape filtering of diffuse and point sources but also on “instream” processes that may transform, immobilise or eliminate diffuse pollutants delivered from land to water (Heathwaite, 2010). More research is needed to solve remaining uncertainties and pollution sources. Ideally, an integrated approach including surveys on other biological descriptors (phytobenthos, macrophytes, fish) and in situ experimental designs, namely directed for the study of river ecological processes (e.g. leaf litter processing), should be developed.

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Anexos

Table A.1 – Physical and chemical parameters recorded at Mau River (6 sampling stations) in May 2005. * stands for missing data.

May 2005	**Sampling station**					
Parameter	**1**	**2**	**3**	**4**	**5**	**6**
pH	5.65	5.91	5.99	6.88	6.87	6.87
O_2 (mg L^{-1})	11.20	11.50	10.90	11.80	11.50	11.30
Temperature (ºC)	12.10	13.20	13.10	12.70	13.10	13.30
Conductivity (µS/cm)	*	61.40	52.00	66.90	57.90	71.80
Section width (m)	1.50	4.40	3.40	4.90	9.50	4.00
Water depth (m)	0.20	0.25	0.25	0.25	0.18	0.25
TSS (mg L^{-1})	6.37	5.23	5.97	2.54	3.78	4.16
Amonia (mg L^{-1})	0.00	0.00	0.01	0.19	0.00	0.01
Nitrates (mg L^{-1})	0.30	1.00	1.10	1.20	1.40	1.40
Nitrites (mg L^{-1})	0.00	0.00	0.01	0.00	0.00	0.01
Phosphates (mg L^{-1})	0.13	0.22	0.20	0.17	0.22	0.17
Sulfates (mg L^{-1})	0.00	1.00	2.00	1.00	1.00	8.00
Transparency	clear	clear	clear	clear	clear	clear

Table A.2 – Physical and chemical parameters recorded at Mau River (6 sampling stations) in August 2005.

August 2005	**Sampling station**					
Parameter	**1**	**2**	**3**	**4**	**5**	**6**
pH	8.65	7.40	7.83	7.57	7.85	7.61
O_2 (mg L^{-1})	8.40	8.50	9.10	13.50	8.60	11.60
Temperature (ºC)	14.50	16.30	16.30	16.70	16.50	18.00
Conductivity (µS/cm)	24.30	64.60	71.10	77.80	66.70	77.30
Section width (m)	1.00	1.50	4.00	3.70	9.20	3.60
Water depth (m)	0.20	0.20	0.20	0.20	0.15	0.10
TSS (mg L^{-1})	2.67	2.28	2.60	1.38	0.48	1.24
Amonia (mg L^{-1})	0.01	0.00	0.00	0.03	0.00	0.00
Nitrates (mg L^{-1})	0.20	1.20	1.60	1.30	1.30	1.30
Nitrites (mg L^{-1})	0.00	0.01	0.01	0.01	0.01	0.00
Phosphates (mg L^{-1})	0.12	0.12	0.11	0.15	0.09	0.12
Sulfates (mg L^{-1})	1.00	7.00	7.00	12.00	8.00	10.00
Transparency	clear	clear	clear	clear	clear	clear

Table A.3 – Physical and chemical parameters recorded at Mau River (6 sampling stations) in November 2005.

November 2005	Sampling station					
Parameter	**1**	**2**	**3**	**4**	**5**	**6**
pH	7.08	7.01	6.66	6.68	6.85	6.74
O_2 (mg L^{-1})	10.12	11.02	9.95	11.11	10.96	11.21
Temperature (ºC)	9.60	10.80	10.70	10.10	9.50	9.10
Conductivity (µS/cm)	23.80	50.50	44.60	49.80	55.20	58.30
Section width (m)	2.30	5.30	3.30	3.80	4.90	3.60
Water depth (m)	0.40	0.30	0.20	0.10	0.30	0.20
TSS (mg L^{-1})	1.34	3.16	3.88	2.19	1.79	2.18
Amonia (mg L^{-1})	0.00	0.00	0.00	0.00	0.28	0.04
Nitrates (mg L^{-1})	0.07	0.07	0.09	0.08	0.08	0.09
Nitrites (mg L^{-1})	0.00	0.00	0.01	0.00	0.01	0.03
Phosphates (mg L^{-1})	0.14	0.37	0.40	0.65	1.06	0.94
Sulfates (mg L^{-1})	6.00	1.00	0.00	7.00	9.00	6.00
Transparency	clear	clear	clear	clear	clear	clear

Table A.4 – Physical and chemical parameters recorded at Mau River (6 sampling stations) in February 2006.

February 2006	Sampling station					
Parameter	**1**	**2**	**3**	**4**	**5**	**6**
pH	6.55	6.70	7.21	7.49	7.04	7.22
O_2 (mg L^{-1})	12.39	13.09	18.40	18.35	13.70	11.68
Temperature (ºC)	9.40	10.80	10.90	10.70	10.90	10.10
Conductivity (µS/cm)	33.20	49.00	57.60	63.70	58.80	67.70
Section width (m)	2.50	4.30	5.70	5.40	7.00	4.00
Water depth (m)	0.35	0.30	0.40	0.40	0.30	0.30
TSS (mg L^{-1})	54.95	41.24	5.00	6.13	9.89	4.37
Amonia (mg L^{-1})	0.00	0.00	0.00	0.02	0.00	0.01
Nitrates (mg L^{-1})	0.07	0.07	0.08	0.08	0.08	0.09
Nitrites (mg L^{-1})	0.01	0.00	0.00	0.01	0.00	0.00
Phosphates (mg L^{-1})	0.13	0.12	0.20	0.15	0.13	0.35
Sulfates (mg L^{-1})	1.00	6.00	1.00	8.00	0.00	8.00
Transparency	clear	clear	clear	clear	clear	clear

Table A.5 – Sediment metal concentrations (in µg Kg^{-1}) of Mau River (6 sampling stations) in May 2005.

May 2005	Sampling station					
Metal	**1**	**2**	**3**	**4**	**5**	**6**
B	332	374	258	314	476	338
Al	456	3442	1512	610	2312	728
V	1.36	7.20	3.40	1.44	5.80	4.20
Cr	1.26	4.80	1.62	0.96	2.20	1.72
Mn	118	122	86.0	196	286	40.0
Fe	296	6134	1334	888	1978	674
Ni	6.80	16.2	4.00	6.20	16.0	14.4
Cu	3.20	9.60	4.60	2.80	7.40	3.80
Zn	400	368	166	178	344	132
As	0.40	3.20	1.38	1.00	6.40	1.38
Sr	46.0	58.0	72.0	52.0	56.0	62.0
Cd	0.34	1.18	<0,1	0.12	0.12	1.14
Ba	714	868	824	424	818	628
Pb	2.40	860	15.2	64.0	206	5.40

Table A.6 – Sediment metal concentrations (in µg Kg^{-1}) of Mau River (6 sampling stations) in August 2005.

August 2005	Sampling station					
Metal	**1**	**2**	**3**	**4**	**5**	**6**
B	482	410	1134	318	354	41.0
Al	22926	16410	40434	78200	27574	5712
V	25.1	<2	57.6	118	<2	<2
Cr	21.0	<2	39.8	90.2	32.0	<2
Mn	288	143	306	672	646	79.6
Fe	17502	13940	35402	75716	35480	7864
Ni	<20	<20	<20	<20	<20	<20
Cu	12.08	<20	22.2	<20	<20	<20
Zn	230	150	195	546	332	103
As	3.46	3.84	11.6	30.8	17.5	4.60
Sr	10.86	13.5	27.8	33.0	26.2	4.28
Cd	<2	<2	<2	<2	0.860	<2
Ba	570	756	896	1310	552	158
Pb	16.6	<20	128	2596	2566	842

Table A.7 – Sediment metal concentrations (in µg Kg^{-1}) of Mau River (6 sampling stations) in November 2005.

November 2005	Sampling station					
Metal	**1**	**2**	**3**	**4**	**5**	**6**
B	342	236	275	103	150	128
Al	10654	1028.8	8734	2290	1218	398
V	8.24	<2	9.26	4.53	<2	<2
Cr	7.55	<2	9.40	3.91	2.36	<2
Mn	59.3	40.3	85.4	33.2	32.5	44.3
Fe	4762	1380	5886	4448	2024	748
Ni	<20	<20	<20	<20	<20	<20
Cu	22.2	<20	27.8	<20	<20	<20
Zn	248	377	316	143	213	171
As	3.92	2.06	6.04	4.17	3	2.90
Sr	15.2	43.0	22.9	14.4	22.3	21.6
Cd	<2	<2	<2	<2	10.6	<2
Ba	377	786	552	496	697	384
Pb	21.7	<20	49.7	288	220	80.5

Table A.8 – Sediment metal concentrations (in µg Kg^{-1}) of Mau River (6 sampling stations) in February 2006.

February 2005	Sampling station					
Metal	**1**	**2**	**3**	**4**	**5**	**6**
B	<20	<20	545	1216	998	587
Al	1511	75.9	589	887	1872	2492
V	1.52	2.21	0.95	1.71	3.28	5.13
Cr	0.862	0.268	0.54	1.09	2.00	3.42
Mn	231	22.6	150	875	73.9	153
Fe	976	38.4	488	2032	1942	3834
Ni	1.61	1.11	0.972	4.71	2.59	5.94
Cu	2.06	4.18	2.11	9.58	5.19	10.9
Zn	5.61	< 4	13.4	47.0	62.4	121
As	1.47	1.64	1.71	2.78	2.23	3.51
Sr	7.1	83.1	8.03	21.1	10.2	13.4
Cd	0.22	0.10	0.16	0.616	0.30	0.484
Ba	11.9	27.3	12	14.0	55.2	65.3
Pb	1.77	0.95	8.35	303	147	610

Table A.9 – Benthic macroinvertebrate *taxa* collected in Mau River (6 sampling stations) in May 2005, with abbreviations (Abbr.) for DCA (continues next page).

					Sampling stations					
Taxonomical group	**Class / Order**	**Family**	**Genus / Species**	**Abbr.**	**1**	**2**	**3**	**4**	**5**	**6**
PLATYHELMINTHES	**Tricladida**	Dugesiidae	Dugesia	Dug		6		2		22
	Tricladida	Planariidae	Planaria	Plan				2		
	Tricladida	Planariidae	Polycelis	Pol		28		16		36
	Tricladida	n.i.		Tric				2		2
ANNELIDA	**Hirudinea**	Erpobdellidae	Dina lineata	Dina li		1				
	Hirudinea	Erpobdellidae	Dina sp.	Dina			1			
	Hirudinea	Erpobdellidae	Erpobdella	Erpblla		1				
	Hirudinea	Erpobdellidae	n.i.	Erpob	1		1			
	Hirudinea	Glossiphoniidae	Glossiphonia	Glossnia			1			
	Hirudinea	Glossiphoniidae	n.i.	Gloss						
	Oligochaeta	Enchytraeidae		Enchy		2	2		1	
	Oligochaeta	Lumbricidae	Eiseniella tetraedra	Eistetra		1				
	Oligochaeta	Lumbricidae	Eiseniella sp.	Eisen						
	Oligochaeta	Lumbricidae	n.i.	Lumbrici		5	6		4	
	Oligochaeta	Lumbriculidae		Lumbricu		7	12	6	1	12
	Oligochaeta	Naididae	Pristina	Prist						
	Oligochaeta	Naididae	n.i.	Naid						
	Oligochaeta	Tubificidae		Tubif		1		2		
MOLLUSCA	**Bivalvia**	Sphaeriidae	Pisidium	Pisid		5				
	Gastropoda	Hydrobiidae	Bythinella	Bythi						
	Gastropoda	Hydrobiidae	Potamopyrgus antipodarum	Potam		47	92			
	Gastropoda	Lymnaeidae	Lymnaea	Lymna						
	Gastropoda	Lymnaeidae	n.i.	Lymnaeid						
	Gastropoda	Physidae	Physa	Phys		9				
	Gastropoda	Planorbidae	Ancylus	Ancy						7
ARACHNIDA	**Acari**	Hidracarina		Hidrac	3	3	7	69	12	44
CRUSTACEA	**Isopoda**	Asellidae	Aselus	Ase	1					
INSECTA	**Coleoptera**	Dryopidae	Dryops (adults)	Dryo ad						
	Coleoptera	Dryopidae	Dryops (larvae)	Dryo lar						
	Coleoptera	Dytiscidae	(adults)	Dyt ad	1					
	Coleoptera	Dytiscidae	(larvae)	Dyt lar						
	Coleoptera	Dytiscidae	sp.2 (adults)	Dyt ad2						
	Coleoptera	Elmidae	Dupophilus (adults)	Dupo ad		1		51	59	41
	Coleoptera	Elmidae	Dupophilus (larvae)	Dupo lar		27	72	106	113	360
	Coleoptera	Elmidae	Elmis (adults)	Elm ad		2	1	12	1	58
	Coleoptera	Elmidae	Elmis (larvae)	Elm lar	21	51	16	3	7	59
	Coleoptera	Elmidae	Esolus (adults)	Eso ad		1		15	23	4
	Coleoptera	Elmidae	Esolus (larvae)	Eso lar		18	14	3	31	10
	Coleoptera	Elmidae	Hydraena (adults)	Hydr ad	3		1	10	3	25
	Coleoptera	Elmidae	Hydraena sp.2 (adults)	Hydr ad2						6
	Coleoptera	Elmidae	Limnius sp.1 (adults)	Lim ad1		2		3		5
	Coleoptera	Elmidae	Limnius sp.2 (adults)	Lim ad2	2	1				
	Coleoptera	Elmidae	Normandia (adults)	Norm ad						2
	Coleoptera	Elmidae	Normandia (larvae)	Norm lar	19	36	20	1	2	14
	Coleoptera	Elmidae	Oulimnius (adults)	Ouli ad		2	1	44	40	35
	Coleoptera	Elmidae	Oulimnius (larvae)	Ouli lar		11	8	2	20	16
	Coleoptera	Elmidae	Riolus (adults)	Rio ad						
	Coleoptera	Elmidae	Riolus (larvae)	Rio lar						
	Coleoptera	Elmidae	n.i. (larvae)	Elmd lar		1				
	Coleoptera	Gyrinidae	(larvae)	Gyr lar		2		2	3	2
	Coleoptera	Helodidae	Helodes (larvae)	Hel lar						
	Coleoptera	Helodidae	n.i. (larvae)	Helo lar	40	1			5	
	Coleoptera	Helophoridae	Helophorus (adults)	Helop ad	1					
	Coleoptera	Hydraenidae	Limnebius (adults)	Limnb ad						
	Coleoptera	Hydrophilidae	(adults)	Hydp ad						1
	Coleoptera	Scirtidae	Hydrocyphon (larvae)	Hydc lar						
	Coleoptera	n.i.		Coleo						1
	Diptera	Anthomyiidae		Anthom						
	Diptera	Athericidae	Atherix	Athex	3	7	24	48	34	5
	Diptera	Athericidae	Atrichops	Atri		10	3	21	1	1
	Diptera	Athericidae	n.i.	Athe	1					
	Diptera	Blephariceridae		Blepha	1					
	Diptera	Ceratopogonidae	Atrichopogon	Atrich						1
	Diptera	Ceratopogonidae	n.i.	Cerato	4	3	9	7	9	33
	Diptera	Chironomidae	Chironomus	Chironus						
	Diptera	Chironomidae	Corynoneura	Coryn						
	Diptera	Chironomidae	sF. Diamesinae	Diame			35			
	Diptera	Chironomidae	sF. Orthocladiinae	Ortho	112	93	58	12	45	269
	Diptera	Chironomidae	sF. Tanypodinae	Tanyp	41	68	113	28	79	60
	Diptera	Chironomidae	tr. Chironomini	Chironi	8	1	24		12	1
	Diptera	Chironomidae	tr. Tanytarsini	Tanyi	49	34	4	15	46	117
	Diptera	Chironomidae	n.i.	Chiro	1	2	16	1	5	14

Taxonomical group	Class / Order	Family	Genus / Species	Abbr.	1	2	3	4	5	6
	Diptera	Dixidae	Dixa	Dixa		1	1			
	Diptera	Dixidae	Dixella	Dixlla						
	Diptera	Dixidae	n.i.	Dixi						
	Diptera	Dolichopodidae		Dolich		5				
	Diptera	Empididae	sF. Hemerodromiinae	Hemer		6	2	10	21	12
	Diptera	Empididae	Chelifera	Chelif						
	Diptera	Empididae	sF. Atalantinae	Atala						1
	Diptera	Limoniidae	Eloeophila	Eloe						
	Diptera	Limoniidae	Hexatoma	Hexat	1		1			
	Diptera	Limoniidae	Rhypholophus	Rhyph						
	Diptera	Limoniidae	Scleroprocta	Scler					1	
	Diptera	Limoniidae	n.i.	Limo	2					
	Diptera	Pediciidae	Dicranota	Dicra						
	Diptera	Psychodidae		Psycho	1					
	Diptera	Psychodidae	sp. 2	Psycho2						
	Diptera	Simuliidae		Simu	6	35	3	29	696	46
	Diptera	Tabanidae		Taba					1	
	Diptera	Tipulidae	Tipula	Tipul						
	Diptera	Tipulidae	sp2	Tipul2						
	Diptera	Tipulidae	n.i.	Tipu			1			
	Diptera	n.i.		Dipt	13	11	7	2	1	87
	Ephemeroptera	Baetidae	Baetis	Btis	7	16	4	16	18	9
	Ephemeroptera	Baetidae	n.i.	Baet	4	4	10	1	8	3
	Ephemeroptera	Caenidae	Caenis	Caen		3	2			1
	Ephemeroptera	Ephemerellidae	Ephemerella	Ephella	45	171	46	12	144	43
	Ephemeroptera	Ephemerellidae	n.i.	Ephemell						
	Ephemeroptera	Ephemeridae	Ephemera	Ephemra		66	42	5		
	Ephemeroptera	Heptageniidae	Ecdyonurus	Ecdy	3					
	Ephemeroptera	Heptageniidae	Epeorus	Epeo	4	36	1	6	31	28
	Ephemeroptera	Heptageniidae	n.i.	Hepta	3	8		1	4	2
	Ephemeroptera	Leptophlebiidae	Centroptilum	Centrop						
	Ephemeroptera	Leptophlebiidae	Habrophlebia	Habrop	8	7	1	1		
	Ephemeroptera	Leptophlebiidae	Paraleptophlebia	Paralep	7	5		7	6	
	Ephemeroptera	Leptophlebiidae	n.i.	Lepto	17	4			32	3
	Ephemeroptera	n.i.		Ephem	24	101	25	4	43	2
	Heteroptera	Gerridae	Gerris	Gerr						
	Heteroptera	Mesoveliidae	Mesovelia	Meso						
	Heteroptera	Notonectidae	Notonecta	Noto						
	Megaloptera	Sialidae	Sialis	Sai	1					
	Odonata	Aeshnidae		Aesh	2			9	29	2
	Odonata	Calopterygidae	Agrion	Agr	2	7	2			
	Odonata	Cordulegasteridae	Cordulegaster	Cordu	6	7	5	6		1
	Odonata	Gomphidae		Gomp			1	2	27	8
	Odonata	Libellulidae		Libell						
	Odonata	Platycnemididae	Platycnemis	Platyc						
	Odonata	n.i.		Odo		1	1	3		
	Plecoptera	Chloroperlidae		Chloro	22			1		
	Plecoptera	Leuctridae		Leuc	106	173	82	57	46	8
	Plecoptera	Nemouridae	Amphinemura	Amphi						
	Plecoptera	Nemouridae	Nemoura	Nem						
	Plecoptera	Nemouridae	Protonemura	Proton	16	4		5	56	2
	Plecoptera	Nemouridae	n.i.	Nemae	1					
	Plecoptera	Perlidae	Perla	Per		1				
	Plecoptera	Perlodidae		Perlo						
	Plecoptera	n.i.		Plec						
	Trichoptera	Beraeidae		Bera	4	1				
	Trichoptera	Brachycentridae		Brachy		4		3		
	Trichoptera	Calamoceratidae		Calam		4				
	Trichoptera	Glossosomatidae		Glosso	9	13	12	163	285	74
	Trichoptera	Goeridae		Goe		1				
	Trichoptera	Helicopsychidae		Helic						
	Trichoptera	Hydropsychidae		Hydrpsy	11	18	13	2	6	18
	Trichoptera	Hydroptilidae		Hydrop	1					
	Trichoptera	Lepidostomatidae		Lepid			1			
	Trichoptera	Leptoceridae		Leptc						
	Trichoptera	Limnephilidae	sF. Limnephilinae	Limnen	28		1			
	Trichoptera	Limnephilidae	tr. Limnephilini	Limni						
	Trichoptera	Limnephilidae	n.i.	Limnep	2		1			
	Trichoptera	Odontoceridae	Odontocerum	Odont						
	Trichoptera	Philopotamidae		Philo	13	6	1	1		1
	Trichoptera	Polycentropodidae		Polycen		5	4	1	6	4
	Trichoptera	Psychomyiidae		Psych	2	4	3			
	Trichoptera	Rhyacophilidae	Ryacophila	Rya	3	19	10		4	4
	Trichoptera	Sericostomatidae		Seri	1	9	12	28	2	4
	Trichoptera	Thremmatidae	Thremma	Thre		39	3	3	1	3
	Trichoptera	n.i.		Tricho	1	8	3	1	1	4

Table A.10 – Benthic macroinvertebrates *taxa* collected in Mau River (6 sampling stations) in August 2005, with abbreviations (Abbr.) for DCA (continues next page).

					Sampling stations					
Taxonomical group	**Class / Order**	**Family**	**Genus / Species**	**Abbr.**	**1**	**2**	**3**	**4**	**5**	**6**
PLATYHELMINTHES	**Tricladida**	Dugesiidae	Dugesia	Dug		10	1	4		14
	Tricladida	Planariidae	Planaria	Plan						
	Tricladida	Planariidae	Polycelis	Pol		308	1	8		28
	Tricladida	n.i.		Tric						
ANNELIDA	**Hirudinea**	Erpobdellidae	Dina lineata	Dina li						
	Hirudinea	Erpobdellidae	Dina sp.	Dina						
	Hirudinea	Erpobdellidae	Erpobdella	Erpblla						
	Hirudinea	Erpobdellidae	n.i.	Erpob						
	Hirudinea	Glossiphoniidae	Glossiphonia	Glossnia		1				
	Hirudinea	Glossiphoniidae	n.i.	Gloss			1			
	Oligochaeta	Enchytraeidae		Enchy			2	1		
	Oligochaeta	Lumbricidae	Eiseniella tetraedra	Eistetra		1				
	Oligochaeta	Lumbricidae	Eiseniella sp.	Eisen		1	4			
	Oligochaeta	Lumbricidae	n.i.	Lumbrici						
	Oligochaeta	Lumbriculidae		Lumbricu		7	2	18	1	
	Oligochaeta	Naididae	Pristina	Prist		3				
	Oligochaeta	Naididae	n.i.	Naid		1				
	Oligochaeta	Tubificidae		Tubif	2	43	1			
MOLLUSCA	**Bivalvia**	Sphaeriidae	Pisidium	Pisid		2				
	Gastropoda	Hydrobiidae	Bythinella	Bythi						
	Gastropoda	Hydrobiidae	Potamopyrgus antipodarum	Potam	89		61			
	Gastropoda	Lymnaeidae	Lymnaea	Lymna						
	Gastropoda	Lymnaeidae	n.i.	Lymnaeid	2					
	Gastropoda	Physidae	Physa	Phys	20					
	Gastropoda	Planorbidae	Ancylus	Ancy						1
ARACHNIDA	**Acari**	Hidracarina		Hidrac				6		3
CRUSTACEA	**Isopoda**	Asellidae	Aselus	Ase						
INSECTA	**Coleoptera**	Dryopidae	Dryops (adults)	Dryo ad						
	Coleoptera	Dryopidae	Dryops (larvae)	Dryo lar						
	Coleoptera	Dytiscidae	(adults)	Dyt ad						
	Coleoptera	Dytiscidae	(larvae)	Dyt lar		1		4		
	Coleoptera	Dytiscidae	sp.2 (adults)	Dyt ad2				2		2
	Coleoptera	Elmidae	Dupophilus (adults)	Dupo ad		1		4	3	72
	Coleoptera	Elmidae	Dupophilus (larvae)	Dupo lar		31	19	46	13	274
	Coleoptera	Elmidae	Elmis (adults)	Elm ad		2		6		175
	Coleoptera	Elmidae	Elmis (larvae)	Elm lar		6	2	26		252
	Coleoptera	Elmidae	Esolus (adults)	Eso ad			1			6
	Coleoptera	Elmidae	Esolus (larvae)	Eso lar		1	3	5	10	10
	Coleoptera	Elmidae	Hydraena (adults)	Hydr ad		1				41
	Coleoptera	Elmidae	Hydraena sp.2 (adults)	Hydr ad2						
	Coleoptera	Elmidae	Limnius sp.1 (adults)	Lim ad1						9
	Coleoptera	Elmidae	Limnius sp.2 (adults)	Lim ad2						
	Coleoptera	Elmidae	Normandia (adults)	Norm ad						4
	Coleoptera	Elmidae	Normandia (larvae)	Norm lar		3	12		1	11
	Coleoptera	Elmidae	Oulimnius (adults)	Ouli ad		1		4	5	84
	Coleoptera	Elmidae	Oulimnius (larvae)	Ouli lar	1	3		6	15	11
	Coleoptera	Elmidae	Riolus (adults)	Rio ad						
	Coleoptera	Elmidae	Riolus (larvae)	Rio lar		2				
	Coleoptera	Elmidae	n.i. (larvae)	Elmd lar						
	Coleoptera	Gyrinidae	(larvae)	Gyr lar			4	4		1
	Coleoptera	Helodidae	Helodes (larvae)	Hel lar						
	Coleoptera	Helodidae	n.i. (larvae)	Helo lar						
	Coleoptera	Helophoridae	Helophorus (adults)	Helop ad						
	Coleoptera	Hydraenidae	Limnebius (adults)	Limnb ad						
	Coleoptera	Hydrophilidae	(adults)	Hydp ad						
	Coleoptera	Scirtidae	Hydrocyphon (larvae)	Hydc lar						
	Coleoptera	n.i.		Coleo						
	Diptera	Anthomyiidae		Anthom		1				
	Diptera	Athericidae	Atherix	Athex			15	45	9	4
	Diptera	Athericidae	Atrichops	Atri		5	3	4		
	Diptera	Athericidae	n.i.	Athe						
	Diptera	Blephariceridae		Blepha						
	Diptera	Ceratopogonidae	Atrichopogon	Atrich				1		
	Diptera	Ceratopogonidae	n.i.	Cerato						
	Diptera	Chironomidae	Chironomus	Chironus		339				
	Diptera	Chironomidae	Corynoneura	Coryn						
	Diptera	Chironomidae	sF. Diamesinae	Diame	9		5			
	Diptera	Chironomidae	sF. Orthocladiinae	Ortho	152	88	30	35	5	28
	Diptera	Chironomidae	sF. Tanypodinae	Tanyp	128	156	64	80	53	17
	Diptera	Chironomidae	tr. Chironomini	Chironi	301	113	15	29	41	8
	Diptera	Chironomidae	tr. Tanytarsini	Tanyi	48	273	42	218	15	39
	Diptera	Chironomidae	n.i.	Chiro		1		3		

					Sampling stations					
Taxonomical group	**Class / Order**	**Family**	**Genus / Species**	**Abbr.**	**1**	**2**	**3**	**4**	**5**	**6**
	Diptera	Dixidae	Dixa	Dixa						
	Diptera	Dixidae	Dixella	Dixlla						
	Diptera	Dixidae	n.i.	Dixi						
	Diptera	Dolichopodidae		Dolich						
	Diptera	Empididae	sF. Hemerodromiinae	Hemer		1				
	Diptera	Empididae	Chelifera	Chelif						
	Diptera	Empididae	sF. Atalantinae	Atala				2		
	Diptera	Limoniidae	Eloeophila	Eloe						
	Diptera	Limoniidae	Hexatoma	Hexat						
	Diptera	Limoniidae	Rhypholophus	Rhyph						
	Diptera	Limoniidae	Scleroprocta	Scler						
	Diptera	Limoniidae	n.i.	Limo						
	Diptera	Pediciidae	Dicranota	Dicra						
	Diptera	Psychodidae		Psycho		1				
	Diptera	Psychodidae	sp. 2	Psycho2						
	Diptera	Simuliidae		Simu		116	5	16		65
	Diptera	Tabanidae		Taba						
	Diptera	Tipulidae	Tipula	Tipul						
	Diptera	Tipulidae	sp2	Tipul2		2				
	Diptera	Tipulidae	n.i.	Tipu		1				
	Diptera	n.i.		Dipt	5	95	7	20	3	2
	Ephemeroptera	Baetidae	Baetis	Btis		94	10	8	6	422
	Ephemeroptera	Baetidae	n.i.	Baet	2	3	5	7		55
	Ephemeroptera	Caenidae	Caenis	Caen				3		
	Ephemeroptera	Ephemerellidae	Ephemerella	Ephella		27	12	12		18
	Ephemeroptera	Ephemerellidae	n.i.	Ephemell						
	Ephemeroptera	Ephemeridae	Ephemera	Ephemra	1	4	6	13	5	2
	Ephemeroptera	Heptageniidae	Ecdyonurus	Ecdy						3
	Ephemeroptera	Heptageniidae	Epeorus	Epeo		8	3	1	1	88
	Ephemeroptera	Heptageniidae	n.i.	Hepta						
	Ephemeroptera	Leptophlebiidae	Centroptilum	Centrop						
	Ephemeroptera	Leptophlebiidae	Habrophlebia	Habrop	8	3	12			
	Ephemeroptera	Leptophlebiidae	Paraleptophlebia	Paralep		62	10	58	19	52
	Ephemeroptera	Leptophlebiidae	n.i.	Lepto	3	24	6	23	11	16
	Ephemeroptera	n.i.		Ephem		7	2	2		25
	Heteroptera	Gerridae	Gerris	Gerr			5			
	Heteroptera	Mesoveliidae	Mesovelia	Meso	1					
	Heteroptera	Notonectidae	Notonecta	Noto						
	Megaloptera	Sialidae	Sialis	Sai	5					
	Odonata	Aeshnidae		Aesh				3	6	4
	Odonata	Calopterygidae	Agrion	Agr	1	1	1		3	1
	Odonata	Cordulegasteridae	Cordulegaster	Cordu	4		2	2	37	
	Odonata	Gomphidae		Gomp			2	5	9	
	Odonata	Libellulidae		Libell						
	Odonata	Platycnemididae	Platycnemis	Platyc			1			
	Odonata	n.i.		Odo						
	Plecoptera	Chloroperlidae		Chloro						
	Plecoptera	Leuctridae		Leuc	15	39	19	54	10	83
	Plecoptera	Nemouridae	Amphinemura	Amphi						2
	Plecoptera	Nemouridae	Nemoura	Nem	6				1	
	Plecoptera	Nemouridae	Protonemura	Proton		6		17		8
	Plecoptera	Nemouridae	n.i.	Nemae						
	Plecoptera	Perlidae	Perla	Per						
	Plecoptera	Perlodidae		Perlo						
	Plecoptera	n.i.		Plec					1	2
	Trichoptera	Beraeidae		Bera		5				
	Trichoptera	Brachycentridae		Brachy						
	Trichoptera	Calamoceratidae		Calam		2	13	4	4	1
	Trichoptera	Glossosomatidae		Glosso		5	16	42	85	15
	Trichoptera	Goeridae		Goe			1			
	Trichoptera	Helicopsychidae		Helic						
	Trichoptera	Hydropsychidae		Hydrpsy		20	1	24		214
	Trichoptera	Hydroptilidae		Hydrop						83
	Trichoptera	Lepidostomatidae		Lepid			101			
	Trichoptera	Leptoceridae		Leptc						
	Trichoptera	Limnephilidae	sF. Limnephilinae	Limnen	4	22		5	3	
	Trichoptera	Limnephilidae	tr. Limnephilini	Limni		7		9	3	2
	Trichoptera	Limnephilidae	n.i.	Limnep						
	Trichoptera	Odontoceridae	Odontocerum	Odont		2				
	Trichoptera	Philopotamidae		Philo						11
	Trichoptera	Polycentropodidae		Polycen		2	1			2
	Trichoptera	Psychomyiidae		Psych		1		3		2
	Trichoptera	Rhyacophilidae	Ryacophila	Rya		18		1	1	1
	Trichoptera	Sericostomatidae		Seri		92	137	50	6	1
	Trichoptera	Thremmatidae	Thremma	Thre		9	30			2
	Trichoptera	n.i.		Tricho		3	3			1

Table A.11 – Benthic macroinvertebrates *taxa* collected in Mau River (6 sampling stations) in November 2005, with abbreviations (Abbr.) for DCA (continues next page).

					Sampling stations					
Taxonomical group	**Class / Order**	**Family**	**Genus / Species**	**Abbr.**	**1**	**2**	**3**	**4**	**5**	**6**
PLATYHELMINTHES	**Tricladida**	Dugesiidae	Dugesia	Dug		13				26
	Tricladida	Planariidae	Planaria	Plan						
	Tricladida	Planariidae	Polycelis	Pol		144	1			9
	Tricladida	n.i.		Tric		1				
ANNELIDA	**Hirudinea**	Erpobdellidae	Dina lineata	Dina li						
	Hirudinea	Erpobdellidae	Dina sp.	Dina						
	Hirudinea	Erpobdellidae	Erpobdella	Erpblla						
	Hirudinea	Erpobdellidae	n.i.	Erpob						
	Hirudinea	Glossiphoniidae	Glossiphonia	Glossnia		4				
	Hirudinea	Glossiphoniidae	n.i.	Gloss						
	Oligochaeta	Enchytraeidae		Enchy			7	4	1	2
	Oligochaeta	Lumbricidae	Eiseniella tetraedra	Eistetra						
	Oligochaeta	Lumbricidae	Eiseniella sp.	Eisen						
	Oligochaeta	Lumbricidae	n.i.	Lumbrici			5		1	1
	Oligochaeta	Lumbriculidae		Lumbricu		23	48	7	43	149
	Oligochaeta	Naididae	Pristina	Prist						
	Oligochaeta	Naididae	n.i.	Naid	5	1		3		3
	Oligochaeta	Tubificidae		Tubif	4	5	6	20	7	2
MOLLUSCA	**Bivalvia**	Sphaeriidae	Pisidium	Pisid		1	1			
	Gastropoda	Hydrobiidae	Bythinella	Bythi		5	1			
	Gastropoda	Hydrobiidae	Potamopyrgus antipodarum	Potam		157	72			
	Gastropoda	Lymnaeidae	Lymnaea	Lymna		2				
	Gastropoda	Lymnaeidae	n.i.	Lymnaeid						
	Gastropoda	Physidae	Physa	Phys		80	1			
	Gastropoda	Planorbidae	Ancylus	Ancy						
ARACHNIDA	**Acari**	Hidracarina		Hidrac				15		
CRUSTACEA	**Isopoda**	Asellidae	Aselus	Ase						
INSECTA	**Coleoptera**	Dryopidae	Dryops (adults)	Dryo ad			1			
	Coleoptera	Dryopidae	Dryops (larvae)	Dryo lar						
	Coleoptera	Dytiscidae	(adults)	Dyt ad						
	Coleoptera	Dytiscidae	(larvae)	Dyt lar						
	Coleoptera	Dytiscidae	sp.2 (adults)	Dyt ad2					1	
	Coleoptera	Elmidae	Dupophilus (adults)	Dupo ad						19
	Coleoptera	Elmidae	Dupophilus (larvae)	Dupo lar		22	14	6	8	176
	Coleoptera	Elmidae	Elmis (adults)	Elm ad		6				12
	Coleoptera	Elmidae	Elmis (larvae)	Elm lar	11	21	1	9	3	135
	Coleoptera	Elmidae	Esolus (adults)	Eso ad						4
	Coleoptera	Elmidae	Esolus (larvae)	Eso lar		8	1	14		16
	Coleoptera	Elmidae	Hydraena (adults)	Hydr ad		1				7
	Coleoptera	Elmidae	Hydraena sp.2 (adults)	Hydr ad2						
	Coleoptera	Elmidae	Limnius sp.1 (adults)	Lim ad1		1				4
	Coleoptera	Elmidae	Limnius sp.2 (adults)	Lim ad2						
	Coleoptera	Elmidae	Normandia (adults)	Norm ad						
	Coleoptera	Elmidae	Normandia (larvae)	Norm lar	4	2	4	3	2	13
	Coleoptera	Elmidae	Oulimnius (adults)	Ouli ad		1				
	Coleoptera	Elmidae	Oulimnius (larvae)	Ouli lar	2	3	3	76	10	143
	Coleoptera	Elmidae	Riolus (adults)	Rio ad	1					
	Coleoptera	Elmidae	Riolus (larvae)	Rio lar						
	Coleoptera	Elmidae	n.i. (larvae)	Elmd lar						
	Coleoptera	Gyrinidae	(larvae)	Gyr lar	2	3		2		4
	Coleoptera	Helodidae	Helodes (larvae)	Hel lar	1					
	Coleoptera	Helodidae	n.i. (larvae)	Helo lar						
	Coleoptera	Helophoridae	Helophorus (adults)	Helop ad						
	Coleoptera	Hydraenidae	Limnebius (adults)	Limnb ad				1		
	Coleoptera	Hydrophilidae	(adults)	Hydp ad				1		
	Coleoptera	Scirtidae	Hydrocyphon (larvae)	Hydc lar	39		1			1
	Coleoptera	n.i.		Coleo						
	Diptera	Anthomyiidae		Anthom						
	Diptera	Athericidae	Atherix	Athex		1	7	19	7	11
	Diptera	Athericidae	Atrichops	Atri		2	11	42	26	2
	Diptera	Athericidae	n.i.	Athe						
	Diptera	Blephariceridae		Blepha						
	Diptera	Ceratopogonidae	Atrichopogon	Atrich						
	Diptera	Ceratopogonidae	n.i.	Cerato	4	1				
	Diptera	Chironomidae	Chironomus	Chironus						
	Diptera	Chironomidae	Corynoneura	Coryn				2		
	Diptera	Chironomidae	sF. Diamesinae	Diame			7			
	Diptera	Chironomidae	sF. Orthocladiinae	Ortho	171	20	18	81	2	12
	Diptera	Chironomidae	sF. Tanypodinae	Tanyp	38	17	10	15	14	1
	Diptera	Chironomidae	tr. Chironomini	Chironi	60	1	2	36	5	3
	Diptera	Chironomidae	tr. Tanytarsini	Tanyi	201	13	13	202	16	3
	Diptera	Chironomidae	n.i.	Chiro						

					Sampling stations					
Taxonomical group	**Class / Order**	**Family**	**Genus / Species**	**Abbr.**	**1**	**2**	**3**	**4**	**5**	**6**
	Diptera	Dixidae	Dixa	Dixa	1	1		5	1	
	Diptera	Dixidae	Dixella	Dixlla				6		
	Diptera	Dixidae	n.i.	Dixi				1		
	Diptera	Dolichopodidae		Dolich		1	1			
	Diptera	Empididae	sF. Hemerodromiinae	Hemer	1		1	3	1	
	Diptera	Empididae	Chelifera	Chelif	3					
	Diptera	Empididae	sF. Atalantinae	Atala	1					
	Diptera	Limoniidae	Eloeophila	Eloe	2					
	Diptera	Limoniidae	Hexatoma	Hexat	1	1				
	Diptera	Limoniidae	Rhypholophus	Rhyph						
	Diptera	Limoniidae	Scleroprocta	Scler						
	Diptera	Limoniidae	n.i.	Limo						
	Diptera	Pediciidae	Dicranota	Dicra	1					
	Diptera	Psychodidae		Psycho	1					
	Diptera	Psychodidae	sp. 2	Psycho2				2		
	Diptera	Simuliidae		Simu		105	9	12	2	54
	Diptera	Tabanidae		Taba						
	Diptera	Tipulidae	Tipula	Tipul	1	1		1		
	Diptera	Tipulidae	sp2	Tipul2						
	Diptera	Tipulidae	n.i.	Tipu				1		
	Diptera	n.i.		Dipt	11	3	1	23	1	
	Ephemeroptera	Baetidae	Baetis	Btis	15	258	50	9		66
	Ephemeroptera	Baetidae	n.i.	Baet	3	8	4	7	1	8
	Ephemeroptera	Caenidae	Caenis	Caen		1		14		9
	Ephemeroptera	Ephemerellidae	Ephemerella	Ephella	25	70	23	7	2	59
	Ephemeroptera	Ephemerellidae	n.i.	Ephemell						
	Ephemeroptera	Ephemeridae	Ephemera	Ephemra	2	4	69	39	94	84
	Ephemeroptera	Heptageniidae	Ecdyonurus	Ecdy	16			1		
	Ephemeroptera	Heptageniidae	Epeorus	Epeo	2	38	4			38
	Ephemeroptera	Heptageniidae	n.i.	Hepta	1					2
	Ephemeroptera	Leptophlebiidae	Centroptilum	Centrop						
	Ephemeroptera	Leptophlebiidae	Habrophlebia	Habrop						
	Ephemeroptera	Leptophlebiidae	Paraleptophlebia	Paralep	55	1227	67	132	146	368
	Ephemeroptera	Leptophlebiidae	n.i.	Lepto	20	88	43	88	33	62
	Ephemeroptera	n.i.		Ephem						
	Heteroptera	Gerridae	Gerris	Gerr			4	5	3	
	Heteroptera	Mesoveliidae	Mesovelia	Meso						
	Heteroptera	Notonectidae	Notonecta	Noto						1
	Megaloptera	Sialidae	Sialis	Sai	3			1		
	Odonata	Aeshnidae		Aesh		3	1	19	6	8
	Odonata	Calopterygidae	Agrion	Agr	14	5	6	13	3	4
	Odonata	Cordulegasteridae	Cordulegaster	Cordu	6	3		38	12	3
	Odonata	Gomphidae		Gomp		3	3	50	11	6
	Odonata	Libellulidae		Libell				1		
	Odonata	Platycnemididae	Platycnemis	Platyc				3		
	Odonata	n.i.		Odo						
	Plecoptera	Chloroperlidae		Chloro	3					
	Plecoptera	Leuctridae		Leuc	15	1	1	1	6	7
	Plecoptera	Nemouridae	Amphinemura	Amphi					1	2
	Plecoptera	Nemouridae	Nemoura	Nem		1		6	1	4
	Plecoptera	Nemouridae	Protonemura	Proton	36			3	1	1
	Plecoptera	Nemouridae	n.i.	Nemae						
	Plecoptera	Perlidae	Perla	Per						
	Plecoptera	Perlodidae		Perlo						
	Plecoptera	n.i.		Plec						
	Trichoptera	Beraeidae		Bera						
	Trichoptera	Brachycentridae		Brachy						
	Trichoptera	Calamoceratidae		Calam		3		165	100	32
	Trichoptera	Glossosomatidae		Glosso	44		12	97	1	13
	Trichoptera	Goeridae		Goe			2			2
	Trichoptera	Helicopsychidae		Helic						
	Trichoptera	Hydropsychidae		Hydrpsy	3	51	8	4	3	37
	Trichoptera	Hydroptilidae		Hydrop	6			2		1
	Trichoptera	Lepidostomatidae		Lepid			9			
	Trichoptera	Leptoceridae		Leptc				8	2	
	Trichoptera	Limnephilidae	sF. Limnephilinae	Limnen	44	2	6			
	Trichoptera	Limnephilidae	tr. Limnephilini	Limni				37	40	5
	Trichoptera	Limnephilidae	n.i.	Limnep						
	Trichoptera	Odontoceridae	Odontocerum	Odont						
	Trichoptera	Philopotamidae		Philo	11	33	1	5		4
	Trichoptera	Polycentropodidae		Polycen	1	1		3		
	Trichoptera	Psychomyiidae		Psych	19	5		19	1	1
	Trichoptera	Rhyacophilidae	Ryacophila	Rya		24	5			1
	Trichoptera	Sericostomatidae		Seri	14	29	42	15	71	40
	Trichoptera	Thremmatidae	Thremma	Thre		14	2		3	2
	Trichoptera	n.i.		Tricho	5	1			1	1

Table A.12 – Benthic macroinvertebrates *taxa* collected in Mau River (6 sampling stations) in February 2006, with abbreviations (Abbr.) for DCA (continues next page).

					Sampling stations					
Taxonomical group	**Class / Order**	**Family**	**Genus / Species**	**Abbr.**	**1**	**2**	**3**	**4**	**5**	**6**
PLATYHELMINTHES	**Tricladida**	Dugesiidae	Dugesia	Dug	2				2	
	Tricladida	Planariidae	Planaria	Plan						
	Tricladida	Planariidae	Polycelis	Pol	74					1
	Tricladida	n.i.		Tric						
ANNELIDA	**Hirudinea**	Erpobdellidae	Dina lineata	Dina li						
	Hirudinea	Erpobdellidae	Dina sp.	Dina						
	Hirudinea	Erpobdellidae	Erpobdella	Erpblla						
	Hirudinea	Erpobdellidae	n.i.	Erpob						
	Hirudinea	Glossiphoniidae	Glossiphonia	Glossnia		4				
	Hirudinea	Glossiphoniidae	n.i.	Gloss						
	Oligochaeta	Enchytraeidae		Enchy	6			5	1	
	Oligochaeta	Lumbricidae	Eiseniella tetraedra	Eistetra		2				
	Oligochaeta	Lumbricidae	Eiseniella sp.	Eisen						
	Oligochaeta	Lumbricidae	n.i.	Lumbrici	2	14	6	5		2
	Oligochaeta	Lumbriculidae		Lumbricu	16	65	59	196	5	209
	Oligochaeta	Naididae	Pristina	Prist						
	Oligochaeta	Naididae	n.i.	Naid	8	23	33	153	11	251
	Oligochaeta	Tubificidae		Tubif	14	42	24	99	5	9
MOLLUSCA	**Bivalvia**	Sphaeriidae	Pisidium	Pisid		1	2			
	Gastropoda	Hydrobiidae	Bythinella	Bythi		1				
	Gastropoda	Hydrobiidae	Potamopyrgus antipodarum	Potam		355	8	1		
	Gastropoda	Lymnaeidae	Lymnaea	Lymna		7				
	Gastropoda	Lymnaeidae	n.i.	Lymnaeid						
	Gastropoda	Physidae	Physa	Phys		40	1			
	Gastropoda	Planorbidae	Ancylus	Ancy						1
ARACHNIDA	**Acari**	Hidracarina		Hidrac	4	7				4
CRUSTACEA	**Isopoda**	Asellidae	Aselus	Ase						
INSECTA	**Coleoptera**	Dryopidae	Dryops (adults)	Dryo ad						
	Coleoptera	Dryopidae	Dryops (larvae)	Dryo lar		4	1			
	Coleoptera	Dytiscidae	(adults)	Dyt ad						
	Coleoptera	Dytiscidae	(larvae)	Dyt lar						
	Coleoptera	Dytiscidae	sp.2 (adults)	Dyt ad2						
	Coleoptera	Elmidae	Dupophilus (adults)	Dupo ad				2		25
	Coleoptera	Elmidae	Dupophilus (larvae)	Dupo lar	1	11	16	34	18	216
	Coleoptera	Elmidae	Elmis (adults)	Elm ad	1		1	1		20
	Coleoptera	Elmidae	Elmis (larvae)	Elm lar	17	18	4	15	6	99
	Coleoptera	Elmidae	Esolus (adults)	Eso ad				1	2	4
	Coleoptera	Elmidae	Esolus (larvae)	Eso lar		1	4	45	7	34
	Coleoptera	Elmidae	Hydraena (adults)	Hydr ad			2	1	2	16
	Coleoptera	Elmidae	Hydraena sp.2 (adults)	Hydr ad2						
	Coleoptera	Elmidae	Limnius sp.1 (adults)	Lim ad1						4
	Coleoptera	Elmidae	Limnius sp.2 (adults)	Lim ad2						
	Coleoptera	Elmidae	Normandia (adults)	Norm ad						
	Coleoptera	Elmidae	Normandia (larvae)	Norm lar	9	5		10	2	21
	Coleoptera	Elmidae	Oulimnius (adults)	Ouli ad	1					7
	Coleoptera	Elmidae	Oulimnius (larvae)	Ouli lar		5	2	21	9	53
	Coleoptera	Elmidae	Riolus (adults)	Rio ad						
	Coleoptera	Elmidae	Riolus (larvae)	Rio lar						
	Coleoptera	Elmidae	n.i. (larvae)	Elmd lar						
	Coleoptera	Gyrinidae	(larvae)	Gyr lar		1	2	2	1	4
	Coleoptera	Helodidae	Helodes (larvae)	Hel lar						
	Coleoptera	Helodidae	n.i. (larvae)	Helo lar						
	Coleoptera	Helophoridae	Helophorus (adults)	Helop ad						
	Coleoptera	Hydraenidae	Limnebius (adults)	Limnb ad						
	Coleoptera	Hydrophilidae	(adults)	Hydp ad						
	Coleoptera	Scirtidae	Hydrocyphon (larvae)	Hydc lar	65			1	2	1
	Coleoptera	n.i.		Coleo						
	Diptera	Anthomyiidae		Anthom						
	Diptera	Athericidae	Atherix	Athex			2	6	8	12
	Diptera	Athericidae	Atrichops	Atri		4		44	2	4
	Diptera	Athericidae	n.i.	Athe						
	Diptera	Blephariceridae		Blepha			3			3
	Diptera	Ceratopogonidae	Atrichopogon	Atrich						
	Diptera	Ceratopogonidae	n.i.	Cerato	2	3	1	7	3	3
	Diptera	Chironomidae	Chironomus	Chironus						
	Diptera	Chironomidae	Corynoneura	Coryn		3	2	1	1	1
	Diptera	Chironomidae	sF. Diamesinae	Diame						
	Diptera	Chironomidae	sF. Orthocladiinae	Ortho	51	94	60	34	25	80
	Diptera	Chironomidae	sF. Tanypodinae	Tanyp	7	75	30	20	9	7
	Diptera	Chironomidae	tr. Chironomini	Chironi	13	8	17	10	46	3
	Diptera	Chironomidae	tr. Tanytarsini	Tanyi	42	128	55	49	50	50
	Diptera	Chironomidae	n.i.	Chiro			1			

Taxonomical group	Class / Order	Family	Genus / Species	Abbr.	Sampling stations 1	2	3	4	5	6
	Diptera	Dixidae	Dixa	Dixa						
	Diptera	Dixidae	Dixella	Dixlla						
	Diptera	Dixidae	n.i.	Dixi						
	Diptera	Dolichopodidae		Dolich		1	2		2	2
	Diptera	Empididae	sF. Hemerodromiinae	Hemer	3		1	4	8	2
	Diptera	Empididae	Chelifera	Chelif						
	Diptera	Empididae	sF. Atalantinae	Atala						
	Diptera	Limoniidae	Eloeophila	Eloe		1				
	Diptera	Limoniidae	Hexatoma	Hexat	2			1		
	Diptera	Limoniidae	Rhypholophus	Rhyph					1	
	Diptera	Limoniidae	Scleroprocta	Scler					1	
	Diptera	Limoniidae	n.i.	Limo	1			1	1	
	Diptera	Pediciidae	Dicranota	Dicra						
	Diptera	Psychodidae		Psycho			1	2		
	Diptera	Psychodidae	sp. 2	Psycho2						
	Diptera	Simuliidae		Simu	7	544	22	10	42	86
	Diptera	Tabanidae		Taba						
	Diptera	Tipulidae	Tipula	Tipul			1			
	Diptera	Tipulidae	sp2	Tipul2						
	Diptera	Tipulidae	n.i.	Tipu						
	Diptera	n.i.		Dipt	4	2	7	4	1	16
	Ephemeroptera	Baetidae	Baetis	Btis	23	116	77	32	37	219
	Ephemeroptera	Baetidae	n.i.	Baet	14	7	2			12
	Ephemeroptera	Caenidae	Caenis	Caen		4	1	2	1	12
	Ephemeroptera	Ephemerellidae	Ephemerella	Ephella	55	106	36	7	19	74
	Ephemeroptera	Ephemerellidae	n.i.	Ephemell						2
	Ephemeroptera	Ephemeridae	Ephemera	Ephemra		11	16	48	1	7
	Ephemeroptera	Heptageniidae	Ecdyonurus	Ecdy	4			1		
	Ephemeroptera	Heptageniidae	Epeorus	Epeo			6			20
	Ephemeroptera	Heptageniidae	n.i.	Hepta						
	Ephemeroptera	Leptophlebiidae	Centroptilum	Centrop			2			
	Ephemeroptera	Leptophlebiidae	Habrophlebia	Habrop						
	Ephemeroptera	Leptophlebiidae	Paraleptophlebia	Paralep	21	1001	31	50	61	82
	Ephemeroptera	Leptophlebiidae	n.i.	Lepto	8	84	4	2	9	13
	Ephemeroptera	n.i.		Ephem					1	
	Heteroptera	Gerridae	Gerris	Gerr						
	Heteroptera	Mesoveliidae	Mesovelia	Meso						
	Heteroptera	Notonectidae	Notonecta	Noto						
	Megaloptera	Sialidae	Sialis	Sai						
	Odonata	Aeshnidae		Aesh				2	4	3
	Odonata	Calopterygidae	Agrion	Agr	3	9				1
	Odonata	Cordulegasteridae	Cordulegaster	Cordu	7	10	3	11	3	6
	Odonata	Gomphidae		Gomp		2		7	34	15
	Odonata	Libellulidae		Libell						
	Odonata	Platycnemididae	Platycnemis	Platyc						
	Odonata	n.i.		Odo						
	Plecoptera	Chloroperlidae		Chloro	9					
	Plecoptera	Leuctridae		Leuc	10		7	18	5	1
	Plecoptera	Nemouridae	Amphinemura	Amphi				1	3	20
	Plecoptera	Nemouridae	Nemoura	Nem						
	Plecoptera	Nemouridae	Protonemura	Proton	87	6			10	24
	Plecoptera	Nemouridae	n.i.	Nemae						
	Plecoptera	Perlidae	Perla	Per						
	Plecoptera	Perlodidae		Perlo	3					
	Plecoptera	n.i.		Plec						
	Trichoptera	Beraeidae		Bera						
	Trichoptera	Brachycentridae		Brachy						
	Trichoptera	Calamoceratidae		Calam		3	1	2		12
	Trichoptera	Glossosomatidae		Glosso	71	2	135	73	151	28
	Trichoptera	Goeridae		Goe						3
	Trichoptera	Helicopsychidae		Helic		60				
	Trichoptera	Hydropsychidae		Hydrpsy	10	19	13	4	7	19
	Trichoptera	Hydroptilidae		Hydrop	14					
	Trichoptera	Lepidostomatidae		Lepid			4			
	Trichoptera	Leptoceridae		Leptc						1
	Trichoptera	Limnephilidae	sF. Limnephilinae	Limnen	13	3				
	Trichoptera	Limnephilidae	tr. Limnephilini	Limni			1			
	Trichoptera	Limnephilidae	n.i.	Limnep		1				
	Trichoptera	Odontoceridae	Odontocerum	Odont						
	Trichoptera	Philopotamidae		Philo	27	3				34
	Trichoptera	Polycentropodidae		Polycen		2		3	3	3
	Trichoptera	Psychomyiidae		Psych	25	3		2	1	8
	Trichoptera	Rhyacophilidae	Ryacophila	Rya	2	7	5			
	Trichoptera	Sericostomatidae		Seri	9	31	7	44	11	17
	Trichoptera	Thremmatidae	Thremma	Thre		3	2	1		
	Trichoptera	n.i.		Tricho	6	1				